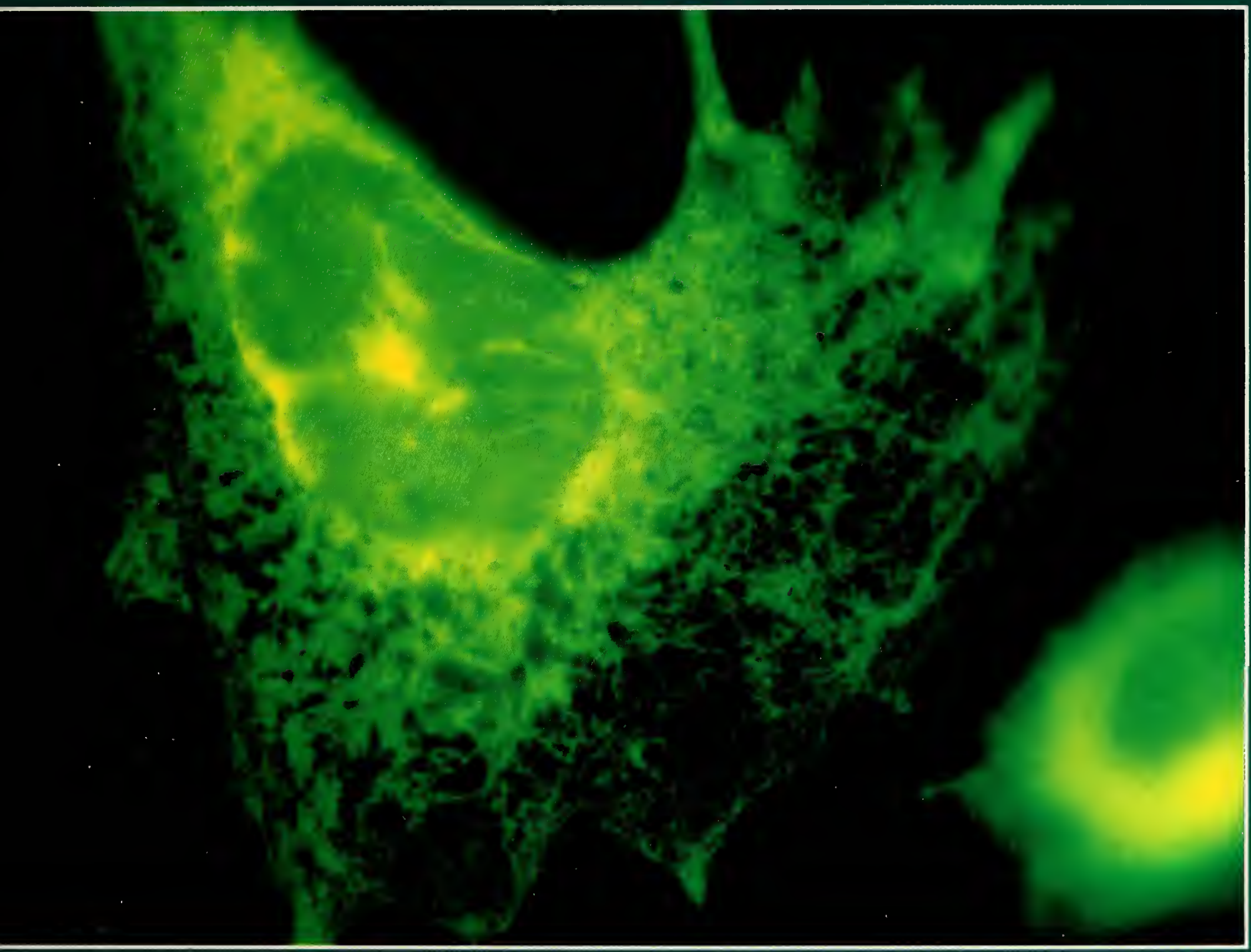


Year Book 85

1985–1986

Carnegie Institution
OF WASHINGTON

Cover: Fluorescence photomicrograph of a baby hamster kidney cell in culture, obtained by Richard E. Pagano of the Department of Embryology in Baltimore. Treatment with a fluorescent lipid labels various intracellular components, including the nuclear envelope (the large shape near the center), the endoplasmic reticulum (the lacelike pattern best seen at the cell's lower right), and the mitochondria (less-focused shapes, seen in the region outside the nucleus). The vertical dimension shown is approximately 20 microns. A second cell is seen at lower right. Pagano and his colleagues employ fluorescent techniques for studying membrane traffic in animal cells.

Carnegie Institution

OF WASHINGTON

Year Book 85

The President's Report

1985–1986

Library of Congress Catalog Card Number 3-16716
International Standard Book Number 0-87279-660-4
Composition by Harper Graphics, Inc., Waldorf, Maryland
Printing by Port City Press, Baltimore, Maryland
December 1986

Contents

President and Trustees

[1]Vice-Chairman to May 9, 1986
[2]Elected Vice-Chairman May 9, 1986
[3]Chairman to May 9, 1986
[4]Elected May 9, 1986

Former Presidents and Trustees

Under the original charter, from the date of organization until April 28, 1904, the following were *ex officio* members of the Board of Trustees: the President of the United States, the President of the Senate, the Speaker of the House of Representatives, the Secretary of the Smithsonian Institution, and the President of the National Academy of Sciences.

Administration and Directors

PRESIDENT AND VICE PRESIDENT
1530 P Street, N.W., Washington, D.C. 20005

James D. Ebert	*President*
Margaret L. A. MacVicar	*Vice President*

DEPARTMENT OF EMBRYOLOGY
115 West University Parkway, Baltimore, Maryland 21210

Donald D. Brown	*Director*

DEPARTMENT OF PLANT BIOLOGY
290 Panama Street, Stanford, California 94305

Winslow R. Briggs	*Director*

GEOPHYSICAL LABORATORY
2801 Upton Street, N.W., Washington, D.C. 20008

Hatten S. Yoder, Jr.	*Director (to June 30, 1986)*
Charles T. Prewitt	*Director (from July 1, 1986)*

MOUNT WILSON AND LAS CAMPANAS OBSERVATORIES
813 Santa Barbara Street, Pasadena, California 91101

George W. Preston	*Director (to June 30, 1986)*
Ray J. Weymann	*Director (from July 1, 1986)*

DEPARTMENT OF TERRESTRIAL MAGNETISM
5241 Broad Branch Road, N.W., Washington, D.C. 20015

George W. Wetherill	*Director*

OFFICE OF ADMINISTRATION
1530 P Street, N.W., Washington, D.C. 20005

John C. Lawrence	*Controller*
Ray Bowers	*Publications Officer; Editor*
Susan Y. Vasquez	*Assistant to the President*
Joseph M. S. Haraburda	*Accounting Manager*
Patricia Parratt	*Associate Editor*
Greg Silsbee	*Grants and Contracts Administrator*
Cady Canapp	*Administrator for Personnel and Employee Benefits*

Marshall Hornblower	*Counsel*

STAFF MEMBER IN SPECIAL SUBJECT AREA

Roy J. Britten

DISTINGUISHED SERVICE MEMBER IN SPECIAL SUBJECT AREA

Barbara McClintock

Carnegie Institution of Washington adheres in all phases of its operations, including employment and educational programs, to a policy barring discrimination on the basis of race, religion, color, national or ethnic origin, age, sex, or physical handicap. In its educational programs it admits qualified students as fellows without regard to race, religion, color, national or ethnic origin, age, sex, or physical handicap to all the rights, privileges, programs, and activities generally accorded or made available to fellows at the Institution. It does not discriminate on the basis of race, religion, color, national or ethnic origin, age, sex, or physical handicap in administration of its educational policies, admissions policies, fellowship programs, and other Institution-administered programs.

President's Commentary

Comet Halley, photographed on 16 March 1986 with the du Pont telescope at Las Campanas by Alan Dressler and Rogier Windhorst. The photo was reproduced from a 20″ × 20″ glass plate, and covers a field more than one degree across. The relatively short exposure time (10 minutes) contributed to the excellent resolution, seen in the highly detailed image of the comet's tail of gas and dust.

. . . . You must have seen
The ships that rose to greet you.
Next time there will be more.
They'll even mount your haggard head
And ride you into Neptune's night!
Yes, we still are bold. . . .
George W. Wetherill
La Serena, Chile
April 1986*

The return of Comet Halley from its 75-year odyssey to the outer reaches of the solar system gave special flavor to the year in science. That practicing scientists of all disciplines seemed to share the public's general fascination with the comet's return, suggested that the curiosity and the awe toward Nature which impel young people toward scientific careers are not dulled in lifetimes of specialized research.

The return of the comet stirred appealing memories for the Carnegie Institution. Seventy-five years ago, in 1910, the comet was observed at the recently built 60-inch telescope at Mount Wilson; it was the year of Andrew Carnegie's visit to Mount Wilson—an event soon followed by Mr. Carnegie's second major endowment to the Institution enabling the building of the now-historic 100-inch telescope. Andrew Carnegie was born 75 years before his California trip—in 1835, the year of Comet Halley's previous visit.

Another milestone event of this report year was an unfortunate one. The loss of Space Shuttle Challenger and its crew produced severe immediate damage to humankind's exploration of space and led to doubts among some scientists and laypersons as to the costs of such activities. The stand-down of Shuttle launches following the disaster meant delays in many scientific investigations; the most obvious setback was an apparent

*Wetherill's full verse is printed on page 115.

two-year delay in the orbiting of the Edwin P. Hubble Space Telescope, whose scheduled launching in August 1986 had been long anticipated by astronomers of Carnegie and other institutions.

Countless other issues confronted makers of science policy. Some such questions raised implications for the Institution's scientific work. Whether biologists should embark on the vast work of sequencing the human genome in its entirety, or whether a better immediate goal is a more generalized mapping, for example, stirred vigorous debate among molecular biologists. Carnegie scientists have expressed strong and open concerns on such matters as our nation's educational decline, the implications of nuclear weaponry for the survival of life on our planet, ill-informed challenges to recombinant DNA research, the mandated teaching of pseudo-science in the public schools of several of our states, and alternative approaches for our future exploration of space. Properly, we are deeply troubled by the gathering plague of Acquired Immune Deficiency Syndrome. My own views on most of these issues are widely known; what is less-often emphasized is that I encourage our directors and staff scientists to contribute their informed perspectives to these debates in appropriate forums. We are part of a magnificent civilization, and our obligations to participate in its workings should not be limited to our quest for society's good will and support.

Our Institution continues in robust health. The Annual Meeting of our trustees on May 9, 1986, was a particularly significant one, marked by the presence of all 24 trustees as well as two trustees emeriti. After reviewing alternative proposals for the future consolidation of the Geophysical Laboratory and Department of Terrestrial Magnetism (DTM), the Board voted authorization to commission an architectural schematic design for new construction and renovation of existing buildings at the campus of DTM in northwestern Washington. The decision resolved uncertainties as to our future in the earth sciences and established a firm course for the future.

Strong affirmations by the trustees also allowed us to move toward early agreement with two distinguished universities for partnership in building and operating the proposed 8-meter telescope in Chile. The signing of a formal agreement with the Johns Hopkins University and the University of Arizona in October 1986 was a satisfying event, as the partnership will open the way for our continued leadership in astronomy for decades ahead. The costs and observing time will be shared as follows: Carnegie 50%, Hopkins 25%, Arizona 25%.

In several ways, the arrangement seems a natural one. Our institution contributes the superb observing site at Las Campanas and our established infrastructure for operating a modern observatory there. Our past success in developing Mount Wilson, Palomar, and Las Campanas must surely have encouraged our new partners to join us.

Meanwhile, Johns Hopkins brings its strong experience in astrophysical research from space vehicles. The Hopkins campus houses the Space Telescope Science Institute, where operational planning and data-processing for the Hubble Space Telescope will be centered. Our scientists of the Department of Embryology have worked closely with Hopkins people for many decades, with superb results.

The University of Arizona contributes its long experience in building and operating major telescopes in remote areas. Arizona also brings its promising new technology for manufacturing large mirrors, and its early contribution to the partnership will be the provision of the 8-meter reflecting mirror. The mirror will be spin-cast by J. Roger Angel and his colleagues in Tucson from molten glass, which assumes a concave shape while being rotated in an oven and cooled gradually.

Much of the credit for the telescope agreement belongs to George W. Preston, director of our Observatories until June 30, 1986, who recognized the opportunity and worked hard to realize it. Preston's successor as director, Ray J. Weymann, comes to us from the University of Arizona, where he took a leading role in the building of the multi-mirror telescope on Mount Hopkins.

Our sense of forward motion in the physical sciences is further reinforced by the appointment of Charles T. Prewitt as director of the Geophysical Laboratory, effective July 1, 1986. He will work with DTM director George Wetherill during the critical next few years, shaping our transition to a new posture in the earth sciences. I look forward enthusiastically to the linking of the distinctive and very great strengths of these two departments. Our future organization will strongly favor the kinds of interdisciplinary approaches that seem required by the most crucial questions in the earth and planetary sciences.

With the meeting of the trustees in May, William Hewlett stepped down after six years of service as Chairman of our Board. The depth of my feelings toward this man are not easily expressed. His tenure as chairman to a great extent coincided with my own presidency, and the progress that the Institution

has achieved in these years—if, as I deeply hope, future historians will look upon these years positively—are heavily attributable to the strong guidance and support characterizing Bill's relation with me. Indeed, I would wish to the future chairmen and presidents of the Institution that they be favored by so effective a bond. The full measure of the Institution's debt to Bill Hewlett cannot be described.

I am of course heartened that Bill will remain as trustee. I am further heartened by the appointments of Richard Heckert as chairman and Robert Seamans as vice-chairman. The past commitment and leadership of these individuals in the affairs of the Institution argues that our future is in good hands.

James D. Ebert
December 15, 1986

The Year in Review

Staff of the Mount Wilson and Las Campanas Observatories. Front row (left to right): Richard Black, Christopher Price, Joan Gantz, Maria Anderson, Wendy Freedman, Robert Georgen, Dee Sahlin. Middle row: Stephen Shectman, Jill Bechtold, Laura Woodard, Eric Persson, Ken Clardy, Jeannie Todd, Estuardo Vasquez, Harvey Crist. Back: Michael Gregg, Rogier Windhorst, Paul Schechter, Stephen Knapp, Jerome Kristian, Robert Jedrzejewski, John Jacobs, Frank Perez, William Qualls, Belva Campbell, John Caldwell, John Adkins, Phil Friswold, Horace Babcock.

The Year in Review

In research work, you cannot plan to make discoveries, but you can plan work which would probably lead to discoveries.

Irving Langmuir
Research Laboratory Bulletin
General Electric Co., Fall 1956

The scientific method, as far as it is a method, is nothing more than doing one's damnedest with one's mind, no holds barred.

Percy W. Bridgman
"The Prospect for Intelligence"
The Yale Review, 1945

Most of the time the process of science is cumulative. New knowledge and understanding are continuously pyramided; old interpretations are constantly questioned and by degrees reshaped.

Occasionally some revolutionary discovery or insight intrudes, breaking the graduated process and producing a fresh intellectual beginning. Our century has seen three such intrusions: the unravelling of the genetic code, the discovery that the Universe is expanding, and the coming together of the plate tectonics synthesis. These were landmark events in recent intellectual history—milestones that continue to provide the frames for today's leading work in biology, astronomy, and the earth sciences, respectively. But it is also true that in each case, most of the necessary building blocks of understanding had been all along present—products of the cumulative nature of science. The final pieces came into place upon the advent of x-ray crystallography, the 100-inch telescope, and radioisotope dating.

The bringing of these new tools to bear on the critical remaining gaps in knowledge was the achievement of individuals having the knowledge, expertise, and imagination to grasp the moment. Such moments are surely rare, but the opportunities for contributions only a little less sweeping seem there for the recognizing. Investigators remain driven to seek out such opportunities, impelled by a

variety of motives ranging from intellectual curiosity to the human competitive urge—to lead through superior and influential work.

Of the many elements going into the attainment of leadership in discovery, perhaps most crucial is the choosing of the research direction—in deciding where and how to devote one's energies. For the individual, the stakes can be high: a poor choice means loss of valuable time and other resources, and may lead to the stagnation of a promising career.

There are, after all, unlimited numbers of possible experiments in molecular genetics, countless galaxies and other celestial objects awaiting observation, multitudes of geological sites and materials for possible investigation. The individual approaching a decision must bring a mastery of existing knowledge, theory, and technique, upon which is applied his or her creativity and imagination—i.e., an ability to break intelligently from established ways of thought. Recognizing some critical gap in knowledge whose solution will confirm or refute a hypothesis, the investigator may see that certain research tools—in equipment, technique, or theory—can be applied to resolve that gap. From such thinking may emerge what is truly a right question, and the investigator's best approach to it.

An important corollary is the investigator's alertness to unforeseen opportunities as an investigation proceeds, perhaps to bend away from the original blueprint. Serendipitous discoveries populate the history of science, and the flexibility to pursue them is really an extension of the mind-processes that set in motion the original investigation. Similarly, since frontier studies entail high risk, there must be willingness to change directions should early results prove unpromising.

An important part of the ideology of the Carnegie Institution is the belief that the choice of research direction is best left to the individual—the conviction that preserving the investigator's freedom and flexibility best assures that worthwhile things will happen. The Institution therefore sets only the general realms of activity. This is done indirectly, primarily through the Institution's choice of staff and fellows, and through its decisions for investing in certain equipment or facilities.

At each of its five research centers, the Institution assembles investigators with varied but interrelating interests, backgrounds, and expertise. As members of different subdisciplines interact informally and begin to think about common questions from different perspectives, loose and changing patterns of collaboration tend to emerge. Thus at Carnegie, the individual's choice of research direction characteristically calls for an ability to link his or her own intellectual growth with that of his or her co-workers, to recognize and exploit opportunities for interdisciplinary focus on questions.

That intellectual adventures of these kinds are taking place should be evident in the discussions of research that follow. The

reader should be able to glimpse the larger purpose in each venture—how results might bear on one or more critical unknowns in some larger question, or how the venture promises significance beyond the limited dimension of the immediate data. The Institution's inclination to proceed with high-risk enterprises in unexplored directions should be recognizable. Every investigation is both product of past choices of direction and prologue to fresh ones.*

The Biological Sciences

Running unmistakably through the work of the biologists of the Carnegie Institution can be detected a continuing fascination with the way things work. This search to understand function runs through the research of ecologists, cell biologists, and practitioners of the newest discipline—molecular biology, which until recently was largely a science of description and structural characterization.

To a biologist interested in broad function, the question of what system to study in detail is extremely critical. How to plan and structure one's research is arguably more critical to biologists than it is to scientists in other fields, for getting to know a living organism, or part of an organism, on which experimentation is to be done is a long and complex process. One must, for example, develop a means of keeping the organism, tissue, or cell alive while doing experiments—and not to violate its integrity in a critical way in the process. This challenge is unique to the biological sciences.

Not only is it important to find a system that can withstand manipulation, it is equally important to find a system offering answers of wide implication. There is a place in biology for the unique, the exceptional (indeed, mutations are a cornerstone of genetics), but one usually chooses a system because of what it may say about biological processes in general. When, for example, Samuel Ward at the Department of Embryology chooses to study the sperm of the worm, he does so not because he is particularly interested in the worm, but because he has found that its sperm cell is an ideal experimental system, one offering insight into

*The essay has been written primarily for readers who are not specialists in the disciplines being discussed; persons interested in scholarly reports are referred to the materials listed in the bibliography (see pages 117–142). The text has been developed from materials provided by the directors and scientists in July 1986.

general developmental processes. Likewise, when Department of Plant Biology staff member Christopher Field studies the physiological ecology of pepper plants, he does so not because pepper plants are particularly fascinating, but because so many different species of pepper plants exist in such a wide range of environments, allowing him to assess adaptations to varying environmental influences and to develop conclusions with broad applicability.

We here begin at the ecological level, and work, with occasional deviations, across a spectrum—first the whole organism, then the cells and cell membranes, then the chromosomes, and finally those tiny segments of chromosomes that are the genes. We will meet scientists as broad-ranging as physiological ecologist Joseph Berry, whose group is devising a complex mathematical approach to the study of photosynthesis while working at the same time to isolate a small molecule that regulates an important plant enzyme, and as focused as Donald Brown, who has spent nearly twenty years on understanding in detail the workings of two genes in the frog-like *Xenopus*.

We will see increased interactions across subdisciplinary boundaries. At the Department of Embryology, for example, a joint project between cell biologist Martin Snider and molecular biologist Steven McKnight has produced the first description of a mammalian cell mutant that is defective in the transport of protein. This research, in combination with that of lipid biologist Richard Pagano, is yielding some fascinating insights into membrane traffic in living cells. Similarly, at the Department of Plant Biology, molecular geneticists, photomorphologists, and physiological ecologists explore many of the same questions. This is especially evident this year in a concentration of study—at several levels—on the pigment-protein phytochrome. There has also recently begun a remarkable collaboration between plant physiologists of the Department and biogeochemists from the Institution's Geophysical Laboratory. The project, which is designed to study oxygen isotope use in plant processes, exploits the strengths of both disciplines: the plant biologists provide carefully prepared plant tissues and enzymes, and the geochemists contribute their experience with stable isotope phenomena.

Stable Isotope Analysis in Plants: A Collaborative Venture

The collaborative effort begun last year by physiological ecologists Joseph Berry and Robert Guy at the Department of Plant Biology and biogeochemists Marilyn Fogel (Estep) and Thomas Hoering of the Geophysical Laboratory bridges the disciplines of biology and geology and brings in the perspectives and precision tools of the geochemist. The work involves experiments on the capacity of certain plant enzymes to discriminate between, or fractionate,

stable isotopes of oxygen in biological reactions of photosynthesis and respiration. In developing stable-isotope measurements as a tool in plant studies, the investigators are increasing understanding of biochemical mechanisms in plants and the evolution of the Earth's oxygen balance.

Oxygen is one of the most abundant elements in the Earth. It occurs as two major isotopes, ^{16}O and ^{18}O. During respiration (i.e., oxygen uptake, or breathing) in microbes and animals, ^{16}O is more likely to be used than the heavier isotope by a factor of 1.018. In experiments in a closed vessel, this preferential use of ^{16}O leads to an accumulation of ^{18}O in the gaseous oxygen, eventually reaching a stable $^{18}O/^{16}O$ value 1.018 times that of the original. (The O_2 becomes enriched in ^{18}O by 18‰.)

This example might be expected to represent what goes on in the Earth, where oxygen is produced by photosynthesis, most of it in seawater, and where most respiration takes place in the atmosphere. In experiments reported last year, the Carnegie investigators confirmed that photosynthesis produces essentially no fractionation in oxygen isotopes. Thus, isotope discrimination in respiration should result in an atmosphere enriched in ^{18}O by 18‰ over the concentration in the oceans. But things are not that simple: there are several different types of respiration, there is non-biological O_2 uptake, and because of water transport in the hydrologic cycle there are variations in the local isotopic composition of water used in photosynthesis. In actuality, the enrichment of ^{18}O in the atmosphere over that in seawater (known as the Dole Effect) is +23.5‰, not +18‰. (See Fig. 1.)

Seeking to understand the causes of the enrichment, the Carnegie investigators are examining the $^{18}O/^{16}O$ discrimination occurring in other types of respiration—in photorespiration in plants, for example, which may consume as much as 40% of a plant's gross oxygen production in photosynthesis. Another mechanism of respiration occurs in plants by a pathway not inhibited by the metabolic poison cyanide. If photorespiration and the cyanide-resistant respiration take up ^{16}O preferentially over ^{18}O, then they may at least partly explain the enhanced ^{18}O of the atmosphere.

During the report year, Berry, Guy, and Fogel did experiments on leaf cells and sampled the oxygen gas above the cultures. This gas was analyzed with an isotope-ratio mass spectrometer (located at NASA's Ames Laboratory, Moffett Field, California) that measures with a precision of 0.001%. They found that these mechanisms do indeed discriminate against ^{18}O: while normal microbial respiration discriminates 16–18‰, photorespiration discriminates about 22–23‰, and the cyanide-resistant respiration discriminates as much as 26–27‰. In vitro studies of enzymes involved (glycolate oxidase and RuBP oxygenase) showed commensurate fractionation.

THE DOLE EFFECT:

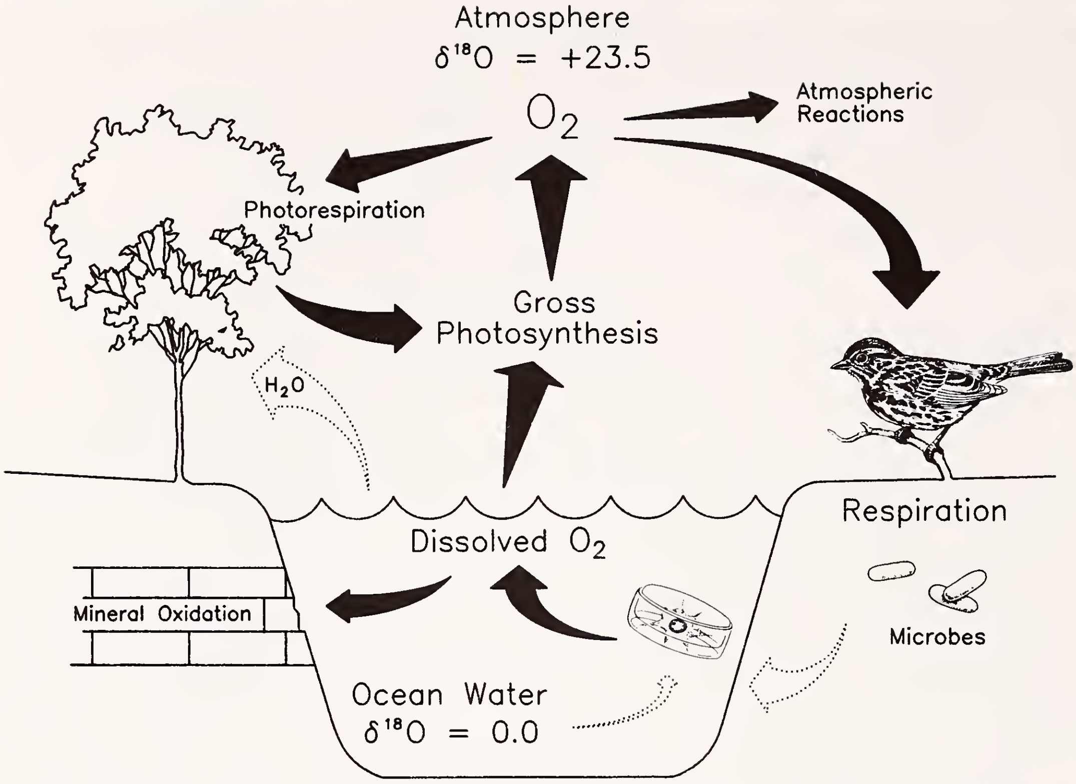


Fig. 1. The ratio of the heavy isotope of oxygen (^{18}O) to the light isotope (^{16}O) is 1.0235 times greater in the Earth's atmosphere than it is in seawater. Joseph Berry and Robert Guy of the Department of Plant Biology, with Marilyn Fogel and Thomas Hoering of the Geophysical Laboratory, are investigating this phenomenon, called the "Dole Effect," in collaborative experiments aimed at determining the differential use, or fractionation, of oxygen isotopes in biological reactions. The drawing above shows the geochemical cycling of oxygen. Oxygen is produced from water during photosynthesis and is consumed in several major uptake reactions, such as photorespiration and dark respiration by plants and respiration by microbes and animals. Solid arrows represent the transfer of oxygen as O_2; dotted arrows represent the transfer of oxygen as water. Enrichment of water as a consequence of transpiration (regulated water loss) by leaves is not shown, but also may contribute to the Dole Effect.

It is not clear if the discrimination observed is universal under all conditions or if its extent could account for the Dole Effect. In future work, the group plans to develop procedures for measuring isotope fractionation during photorespiration among a variety of species as a function of environmental conditions. They also hope to study more-complex systems where more than one process of O_2 exchange is occurring.

Although isotope-abundance measurements have been used for years by biogeochemists to help trace the organic record back through geologic time, they are now becoming a useful tool in biological laboratories. Previous studies of respiration in plants depended on the use of selective inhibitors, which in all probability interfered with normal metabolic processes. The techniques of isotope-fractionation measurement offer a direct and nondestructive method.

Plant Adaptation: Measuring Environmental Variables

> Demonstrations that we understand enough about adaptation to begin predicting the patterns preserved by natural selection provide encouragement that we will soon be able to, at least in principle, "custom design" plants for particular habitats.
>
> Christopher Field
> July 1986

A scientist wishes to separate component parts, to get rid of the nonessentials, to get at the true nature of a thing. The need to quantify, or measure, is at the core of this drive. Nowhere is this more difficult than in biology, especially at the ecological level. For all of life is a vast web, intimately connected to the changing physical environment. How does one separate interdependent processes? How, for example, does one go about assessing the significance of particular adaptive characteristics in real (and hence complex) environments?

This is the question that physiological ecologist Christopher Field of the Department of Plant Biology and research associate Robin Chazdon have been working on during the report year. These two study how plants adapt to one of the most complex of environments—the tropical rain forest. They use as their model system the tropical genus *Piper* (the pepper plant), which inhabits a wide range of environments, from deep shade to full sun. In studying adaptation of *Piper* species, Field and Chazdon are attempting to quantify various resources in the tropical environment, especially that of light.

This year, after experimenting with a variety of methods, they found that the best way to quantify the light environment is to do computer analyses of hemispherical, or "fisheye," photographs. (See Fig. 2.) This method enables them to estimate an annual pattern of light environment for a great many sites. Using the technique, they demonstrated that photosynthetic characteristics of plants in a particular location respond to slow changes in the light environment (over the course of months) but not fast changes (over weeks).

Field has been attempting to plug his data into a mathematical model of photosynthetic carbon balance developed by himself, fellow staff member Joseph Berry, and colleagues. This model is proving useful in identifying the combinations of light environment and nutrient availability in which several *Piper* species should realize high carbon gain. The model has also enabled them to predict, on the same criterion (that of maximizing carbon gain), broad trends in leaf architecture with changing light availability.

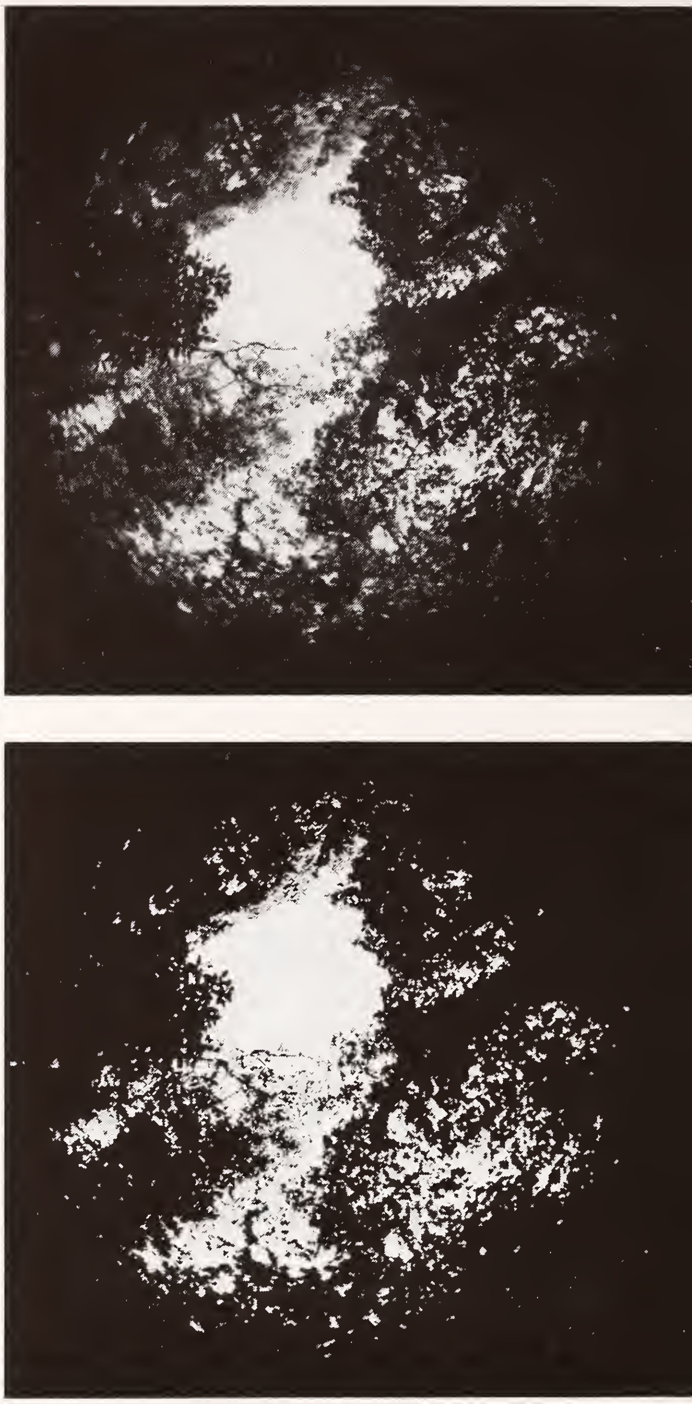


Fig. 2. In quantifying the light environment at the floor of the tropical rainforest, Christopher Field and Robin Chazdon of the Department of Plant Biology use computer analyses of hemispherical photographs of rainforest canopies, such as this one (upper panel), taken in a "gap"—an opening in a forest canopy caused by the fall of a large tree—in Veracruz, Mexico. (A digitized representation of the same photograph is in lower panel.) These horizon-to-horizon views contain the information necessary to describe the light environment of understory seedlings, which do not reach maturity unless a gap forms above them.

Photosynthesis: A Mathematical Approach

Joseph Berry has long been interested in quantitative aspects of photosynthesis. He and his colleagues have been working to draw together a sufficiently comprehensive understanding of photosynthesis in its biochemical and biophysical workings to explain the complex physiological responses seen with whole leaves. The problem they face is how to integrate segments of knowledge—to learn how the parts intermesh and interconnect.

During the report year, in pursuit of this goal, Berry and colleagues concentrated on developing a numerical model explaining how the rate of a complex metabolic process in photosynthesis like

carbon dioxide (CO_2) fixation is determined by the plant's capacity to function efficiently in any one of several sequential steps. (CO_2 fixation is the last of a series of steps in photosynthesis whereby CO_2 is turned into carbohydrates and water.) Several years ago, with visiting investigator Graham Farquhar, Berry developed an early model based on a simplification. They reasoned that, in plants, the maximum rate of any metabolic process was determined by limiting "bottleneck" reactions. Though the model worked well for mathematical analyses of gross physiological responses of intact plants, its underlying assumptions oversimplified the biochemical systems. Any "bottlenecks" in metabolic pathways, they found, tend to occur within a framework of highly regulated reactions that keep the same balance in the flow of metabolites, regardless of the location of the bottleneck.

This was demonstrated experimentally during the report year by Berry, former visiting investigator Tom Sharkey, and former fellow Jeffrey Seemann. (Both Sharkey and Seemann are now at the Desert Research Institute of the University of Nevada.) These three showed that the activity of Rubisco, a major photosynthetic enzyme that combines carbon dioxide with ribulose bisphosphate (RuBP), is regulated by feedback mechanisms so that the plant's capacity to consume RuBP is reduced whenever this capacity exceeds its capacity to manufacture RuBP. The inhibitor of Rubisco discovered in bean plants last year (*Year Book 84*, p. 42) and identified this year by Berry and collaborators George Lorimer and John Pierce of E. I. du Pont de Nemours & Co., is part of one of those feedback mechanisms.

This Rubisco-inhibiting substance is a close structural analog of a molecule formed as an intermediate in the normal reaction catalyzed by Rubisco. Because of this similarity, the inhibitor binds very tightly to the catalytic site, preventing the enzyme from acting upon its normal substrate, RuBP. When regulation is required (for example, in the dark), the concentration of this inhibitor goes up. When regulation is not required, that is, when photosynthesis is at its peak and all of the Rubisco is needed, the inhibitor disappears. The mechanism that regulates the concentration of the inhibitor thus serves to regulate Rubisco. Berry and his colleagues are currently at work investigating this and other regulatory mechanisms.

Application of Control Theory. One pertinent question so far unanswered about such processes is: why should biochemical reactions like that of Rubisco need to be so carefully balanced? To approach this question, Berry needed a much more complete model of the complex biochemical reactions than the one he had. Fortunately, Ian Woodrow had just arrived from the Australian National University, bringing with him a strong interest in the regulation of metabolic pathways. He had just learned a mathematical approach

developed several years earlier by biochemists working in England. This approach, called control theory, had never before been applied to a process as complex as photosynthesis, but Woodrow argued that the mathematical simplifications offered by the theory could be used to simulate the regulatory processes involved in photosynthetic metabolism.

Using methods based on control theory, Woodrow developed a model of photosynthetic carbon dioxide fixation. His analysis demonstrated that in order to maintain a steady state, it is necessary to have a precise balance between input and output reactions of the cycle, while still maintaining optimal concentrations of the intermediate substrates. His work provides a rationale and a quantitative model explaining the need for the elaborate regulatory mechanisms observed in biochemical metabolism.

Berry writes that a major advantage of the control theory approach is that it permits analysis of a system according to its structure, without precise knowledge of how the structure is achieved. Furthermore, he notes, new information may be added at a later date without reworking the existing model. To test and extend the model, Berry, Woodrow, and graduate student Timothy Ball are currently investigating the regulatory mechanisms used by leaf stomatal openings, which control the supply of carbon dioxide needed for the biochemical reactions occurring within. Visiting investigator Engelbert Weis from the University of Düsseldorf, West Germany, is also working with the model, integrating into it the initial, light-driven reactions of photosynthesis.

According to Winslow Briggs, the work going on in Berry's lab "has produced a major step up in our understanding of the overall regulation of photosynthesis." He adds that it also illustrates the importance of maintaining a vigorous exchange program with visiting investigators. "It is quite unlikely that any of the four investigators—Berry, Woodrow, Weis, or Ball—could have brought this program into such elegant focus working in isolation."

Photoinhibition

While Berry has been concentrating on the modeling and quantitative analysis of photosynthetic pathways, his fellow staff members David Fork and Olle Björkman have been continuing their efforts to study what happens to the photosynthetic mechanism when things go wrong, specifically when a plant receives too much light. How does it cope? What can it do to offset the potential damage to its photosynthetic apparatus?

All plants, both sun-loving and shade-loving, are susceptible to this photosynthesis-inhibiting phenomenon, called photoinhibition. Photoinhibition occurs when the photosynthetic pigments are excessively excited by too much light, which the plant cannot

dissipate. Then, damage occurs to the reaction center of photosystem II, one of two photosystems of photosynthesis. If the damage is not repaired, photosynthetic efficiency inevitably declines. Fork studies this process by exploring its mechanisms at the biophysical level, while Björkman takes a more physiological approach.

Recovery from Photoinhibition: Comparing Sun and Shade Plants. Björkman and postdoctoral fellow Barbara Demmig developed during the report year two simple techniques—one based on the photon yield of photosynthetic oxygen evolution, the other on chlorophyll fluorescence—to measure the efficiency by which plants photosynthesize. Björkman and Demmig found that these techniques could also be used to provide quantitative indicators of the extent of photoinhibition. This enabled them to do comparative studies on leaves of many different species of sun and shade plants.

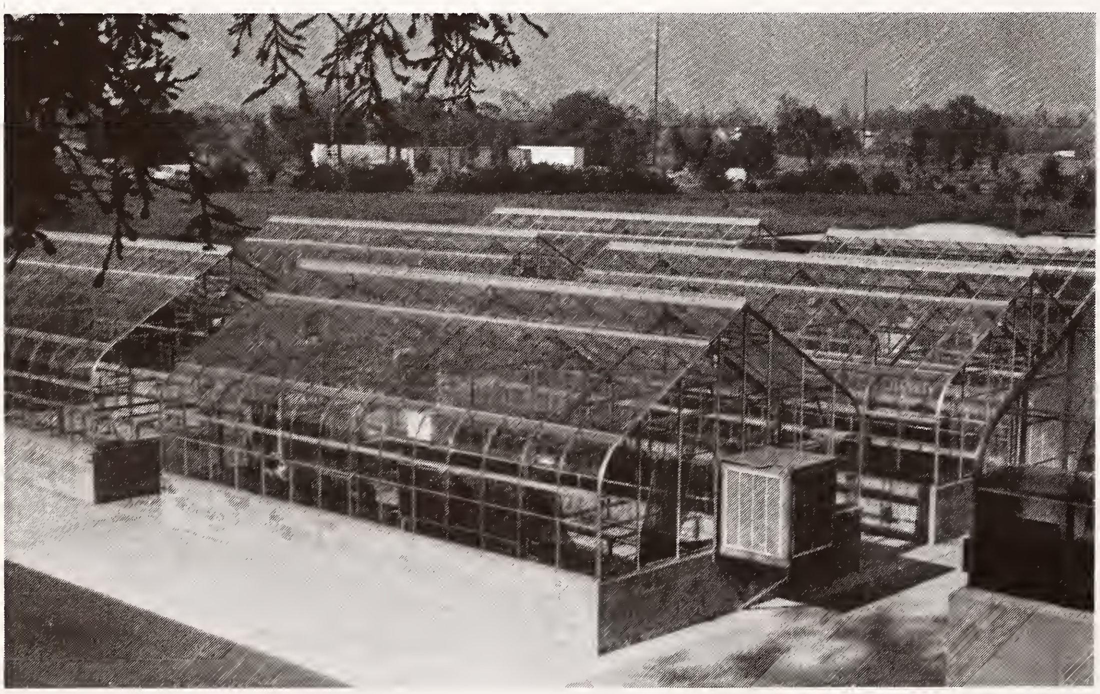
Sun leaves are intrinsically more tolerant of high light stress than are leaves of shade plants. For years it was thought that this tolerance was caused primarily by the greater capacity of sun leaves to do photosynthesis. After surveying some 44 species of plants, however, Björkman and Demmig found that an even more important factor was the greater capacity of sun leaves to recover from photoinhibition—not only after removal of the stress but during it as well. Sun leaves also appear to have another, much more developed protective mechanism at the molecular level, which enables them to dissipate excess light energy harmlessly. This mechanism is not yet characterized.

Recovery from photoinhibition is faster in weak light than it is in total darkness. This was the major result emerging from experiments undertaken last year by Björkman and postdoctoral fellow Max Seyfried. This year, continuing the study, the two investigators found that light levels as low as 0.001 that of normal sunlight stimulated the rate of repair significantly over that occurring in darkness. They also found that the light must be continuous; if removed or interrupted, recovery returns to the dark level. Furthermore, they found that blue and red light are equally effective in stimulating repair, at levels proportional to light absorption by chlorophyll. This suggests that the photoreceptor mediating the recovery process is some form of chlorophyll, rather than the red-light-sensitive phytochrome or a blue light photoreceptor.

Björkman plans to extend studies of photoinhibition to field-growing cotton plants. Cotton is often grown under conditions of high temperature, drought, and high light, and therefore is susceptible to photoinhibition. An interesting feature of cotton plants is that some species can do solar tracking (i.e., their leaves can follow the Sun throughout the day to maximize exposure), and some can not. Björkman plans to compare the two kinds of plants under different environmental conditions.

Fluorescence Monitoring of Photoinhibition. Meanwhile, David Fork continued his pioneering use of fluorescence to monitor the mechanisms of photoinhibition. Last year, he and his colleagues found that a fluorescence decrease accompanies the onset of photoinhibition in plants given excess light. This year, Fork, with visiting investigators Salil Bose and Steven Herbert, discovered that many plants will show a decline in fluorescence even when no photoinhibition is involved. This indicates the presence of a protective mechanism perhaps like the one postulated by Björkman and Demmig. Preliminary experiments indicate that this mechanism dissipates the excess light energy as heat, but the details remain to be elucidated.

Photosynthesis operates most efficiently when the rates of its two photosystem centers of reaction (each of which absorb different wavelengths of light) are in balance. Fork and Bose have found two ways in which that balance is restored if one of the two systems is exposed to a sudden change in light spectral quality (as might occur with low, understory plants in a forest when a tree forming part of a shading green canopy is removed by a storm). Some plants exposed to this sort of imbalance react by changing the relative amount of light absorbed by their two photosystems (presumably by migration of pigment-protein complexes from one photosystem to another). In this case, the antenna pigments adjust their sizes to maintain photochemical balance. In other plants, light absorbed by one photosystem may spill over to the other. Currently, Fork and Bose are probing the changes in membrane constituency resulting from this spillover.



The recently completed greenhouses on the campus of the Department of Plant Biology.

Architecture of the Photosynthetic Apparatus

In order to understand photoinhibition and photoprotection fully, it is necessary to understand the structure of the two photosystems of photosynthesis. Particularly important is photosystem II, the site of photoinhibitory damage. Photosystem II contains chlorophyll, carotenoid pigments, and at least five different proteins. Postdoctoral fellow Akihiko Yamigishi and Fork have recently been successful in isolating the largest of these proteins, which they found can perform the primary photochemical reaction of photosystem II. They are currently examining what other reactions this protein can perform.

Meanwhile, staff member Jeanette Brown continues her long-time interest in the ways that such proteins are assembled with pigments to form functional reaction complexes. During the report year, she and postdoctoral fellow Grazyna Bialek-Bylka found they could incorporate various pigment-protein complexes into dried films of polyvinyl alcohol without disturbing the primary light reactions of photosynthesis. Application of an electric current to the film as it dried preserved a fairly high degree of orientation of the complexes, readily demonstrable with polarized light. The technique should be a powerful one for providing information about the precise geometric relationships between pigments and proteins.

Nutrient Stress and Coping Mechanisms in Cells

The study of stress, particularly that of high light intensity, is a major part of the Department's efforts. But light is not the only potentially stressful environmental influence being studied. Two other projects involve, respectively, high-salt stress and nutrient deprivation.

High Salt in Mangroves. In their continuing study of how Australian mangrove species tolerate natural environments of full-strength seawater, Olle Björkman and Barbara Demmig compared plants grown under conditions of high salt (100% concentration seawater) with those grown under conditions of low salt (10% salt concentration seawater). They found that the high-salt-grown mangroves had a greater capacity (1) to exclude sodium and chloride, and (2) to secrete excess salt through specialized leaf glands. The energy costs of increased secretion and better exclusion are minor, for mangroves maintain the same rates of photosynthesis, water use efficiency, and growth whether grown in 100% or 10% seawater.

Sulfate Deprivation. How do cells sense changes in their nutrient

environment? How do they respond biochemically? Staff member Arthur Grossman and his colleagues found last year that when cells of algae are deprived of sulfate they begin to synthesize membrane machinery to facilitate sulfate uptake. This year, they have made progress in studying various components of this machinery. Graduate student Laura Green has isolated the sulfate-binding protein and other membrane-bound components whose synthesis increases during sulfate deprivation in the primitive alga *Synechococcus*; she has also initiated studies on the genes involved. Eugenio deHostos, meanwhile, has isolated the gene encoding an essential enzyme secreted by a sulfate-stressed green alga, *Chlamydomonas reinhardtii.* He is currently studying what features the gene has that might be of particular importance in its regulation.

Molecular Membrane Traffic in Cells

While scientists at the Department of Plant Biology investigate how plant cells respond to stress, cell biologists at the Department of Embryology focus on how animal cells maintain their separate environments and still function as parts of organic wholes. Especially critical is the cell surface, or plasma membrane, which protects the cells it surrounds and helps maintain communication with other cells. To keep the membrane in working order there is inside the cell an elaborate network of molecules especially designed for shuttling membrane components—the proteins and lipids—back and forth between the membrane and internal parts of the cell. At the Department of Embryology, cell biologists Martin Snider and Richard Pagano have developed novel methods for studying this molecular traffic in exquisite detail.

Transmembrane Lipid Asymmetry. Membranes are dynamic, bilayered matrices whose very shape and bulk properties depend intimately on the chemical make-up of their individual components. The main structural units of membranes are lipids, of which thousands of molecular species exist. Some lipids also appear to have profound effects on cell function; because of this, biochemists and biophysicists have begun to take a new look at these fascinating molecules. One such scientist is Richard Pagano.

Over the years Pagano and his colleagues have developed a powerful means to study lipids. They have learned how to attach fluorescent tags to synthetic lipid analogs, and then follow the movement of these analogs through the cells by fluorescence microscopy. Recently, Pagano's group has been using this technique in mammalian cells to study an interesting but poorly understood phenomenon in membrane biology, which is that some lipid classes are restricted to the outer half of the plasma membrane, while others are found only on the inner, or cytoplasmic, half of the membrane. (The best studied case of this transmembrane asymmetry

is the red blood cell, but Pagano notes that such asymmetry may be a common feature of the membranes of all animal cells.)

Pagano wonders at what point during the life cycle of a lipid its preferential orientation is established—does asymmetry begin at the lipid's intracellular site of synthesis, or is it established only later, once the lipid has traveled to its final site? Further, how does continuous cycling of a lipid between intracellular organelles and the plasma membrane affect its asymmetry? Finally, how is asymmetry maintained once established, and what is its biological function?

To examine asymmetry, he and his colleagues (notably technician Ona Martin, who is especially adept at synthesizing lipid analogs) this year made a fluorescent analog of the lipid phosphatidylserine (PS), and found that it is restricted primarily to the outer leaflet of the plasma membrane at low temperatures (2°C). However, when the cells are briefly warmed to 7°C, the fluorescent PS quickly internalizes, labeling intracellular organelles such as the mitochondria and the nuclear envelope. (See Fig. 3.) PS does not move inside

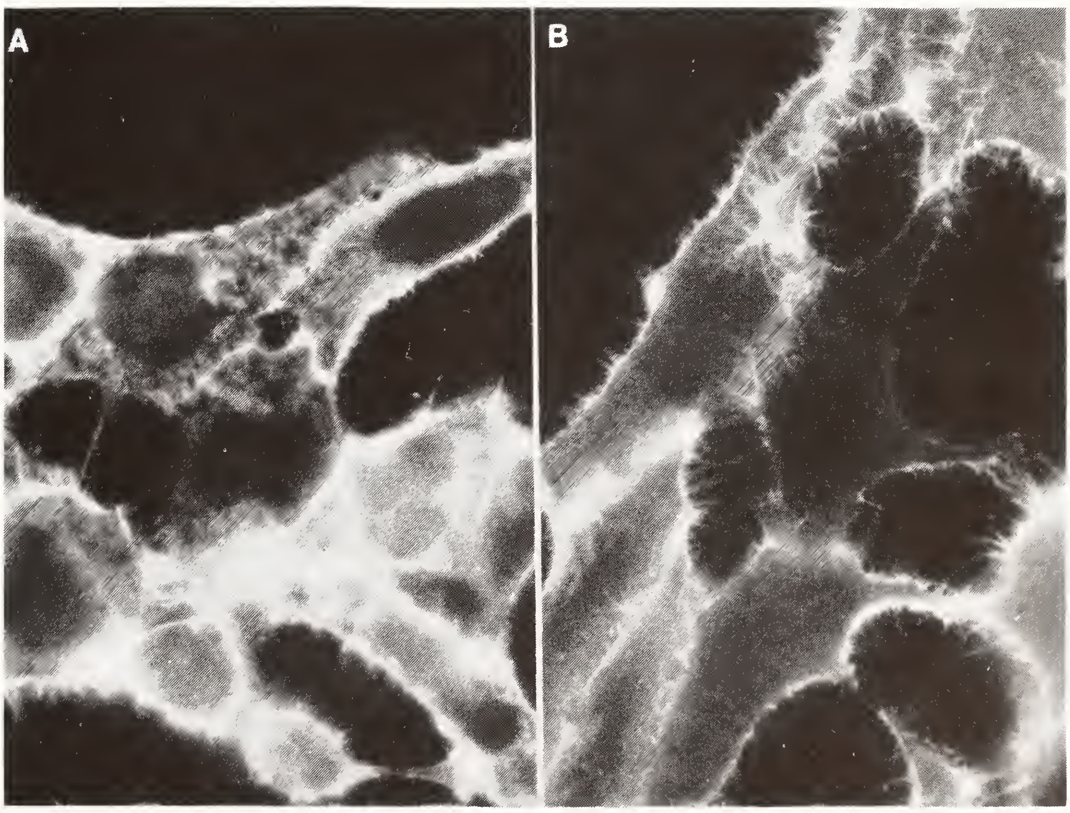


Fig. 3. Richard Pagano and his colleagues at the Department of Embryology find that a fluorescent analog of phosphatidylserine (PS) undergoes rapid translayer movement ("flip-flop") at the plasma membrane of Chinese hamster fibroblasts. The cells are treated with the lipid analog for 30 minutes at 2°C, washed, and then warmed to 7°C for an additional 30 minutes. Photo A, above, shows a fluorescent micrograph of control cells showing labeling of intracellular membranes (mitochondria and the nuclear envelope). In photo B, cells were pretreated with a reagent which derivatizes protein sulfhydryl groups. This inhibited the movement of PS across the membrane, and no intracellular labeling is seen.

by the usual mechanism of endocytosis, where a small portion of the plasma membrane folds inward and encloses extracellular substances in small vesicles which are then internalized, but by a transbilayer "flip-flop" through the membrane.

Pagano and colleagues found that they could inhibit this transbilayer movement by three treatments: (1) if they first lowered cellular ATP levels by treatment with energy poisons, (2) if they pretreated cells with a reagent which reacts with protein sulfhydryl groups, or (3) if they used an unnatural stereoisomer of PS instead. These results strongly suggest to Pagano that a protein near the cell surface plays an important mediating role in the transbilayer movement of PS. The existence of such a mediator has important implications in the maintenance of PS lipid asymmetry. During the coming year, Pagano hopes to characterize further this protein molecule.

Protein Traffic through the Golgi. The proteins embedded in a cell's lipid membrane can be as varied as the lipids themselves. Like lipids, each one of these proteins is originally assembled inside the cell, on a large network of channels called the rough endoplasmic reticulum. Many proteins are used internally, but others are secreted, or transported, to the cell surface, where they serve a variety of functions; some cell surface proteins synthesize macromolecules for export; some bind to and internalize nutrients and hormones; some mediate interactions with neighboring cells. The question that intrigues staff associate Martin Snider is how proteins destined for the cell surface get to the cell surface. What routes do they take? And, once they get to the membrane, what happens to them? Are they degraded or do they recycle?

It is known that cells contain a secretory and endocytic apparatus composed of from ten to twenty types of intracellular, membrane-bound organelles. Before reaching their final destinations in the cell surface membranes, newly made proteins are carried between these internal organelles in transport vesicles, formed by the outward budding of donor membranes that have fused with the protein's receptor. One organelle that all proteins seem to pass through in this way is the Golgi complex. When they emerge from the Golgi, the proteins are extensively modified.

Snider is especially interested in charting the traffic through the Golgi complex. As described in *Year Book 84* (p. 37), he and his colleagues have developed a method of marking the proteins (or, rather, the receptors that carry them) in a way that enables them to determine through which compartment of the Golgi—the distal (closest to the cell surface) or the proximal—the proteins have traveled. Two years ago, Snider had the first intimation that traffic through the Golgi is not unidirectional. He found that not only newly made proteins pass through; so too do proteins *returning* from the cell surface—those bearing, for example, hormones or

nutrients. This was surprising, for the Golgi complex was thought to function primarily in the transport and modification of newly made molecules.

This year, in examining Golgi transport more closely, Snider and colleagues found that proteins returning from the cell surface cycle through the proximal Golgi region not once but several times. In fact, for every newly made molecule passing through for the first time, there are some five to ten recycling molecules. This means that 80–90% of the glycoprotein traffic passing through this organelle is composed of recycling molecules. Snider, who has recently moved to Case Western Reserve University, is pursuing this fascinating discovery by examining the movement of individual proteins.

Meanwhile, he maintains connection to Carnegie in a newly initiated collaboration with staff member Steven McKnight and postdoctoral fellow Frank Tufaro. McKnight and Tufaro are interested in interactions between viruses and their animal host cells. In one approach to this problem, they have begun to isolate host cell mutants that fail to support viral infection. In these cells, some cellular component that is critical to viral expression appears to be missing or defective. In one, where infection is not blocked until a very late stage, Snider and Tufaro have determined that the defect appears to be in the transport of newly made proteins from the endoplasmic reticulum to the cell surface—most probably at the level of the Golgi complex (see Fig. 4). Snider finds this particularly exciting not only because it is the first description of a mammalian cell mutant defective in protein transport, but because the methods developed by McKnight and Tufaro have the potential for generating a large collection of such mutants. This collection will be invaluable, he writes, in dissecting the complex membrane traffic that carries newly made glycoproteins to their final locations.

Chromosomes

The molecules that make up the lipids and proteins are assembled in the cell, but the directions for assembly come from inside the nucleus, where the chromosomes (containing proteins and the genes) provide the necessary information. At the Department of Embryology, two studies involving chromosomes are underway. Joseph Gall studies the structure and function of the extra-large amphibian chromosomes using monoclonal antibodies and a special nucleic acid hybridization technique that he developed many years ago. Meanwhile, staff associate David Schwartz reports a new method, which he developed, that makes it possible to resolve very large DNA molecules, large enough in some cases to correspond to whole chromosomes.

Manipulating Large Molecules of DNA: Pulsed Electrophoresis. The ability to manipulate small DNA molecules has enabled molecular

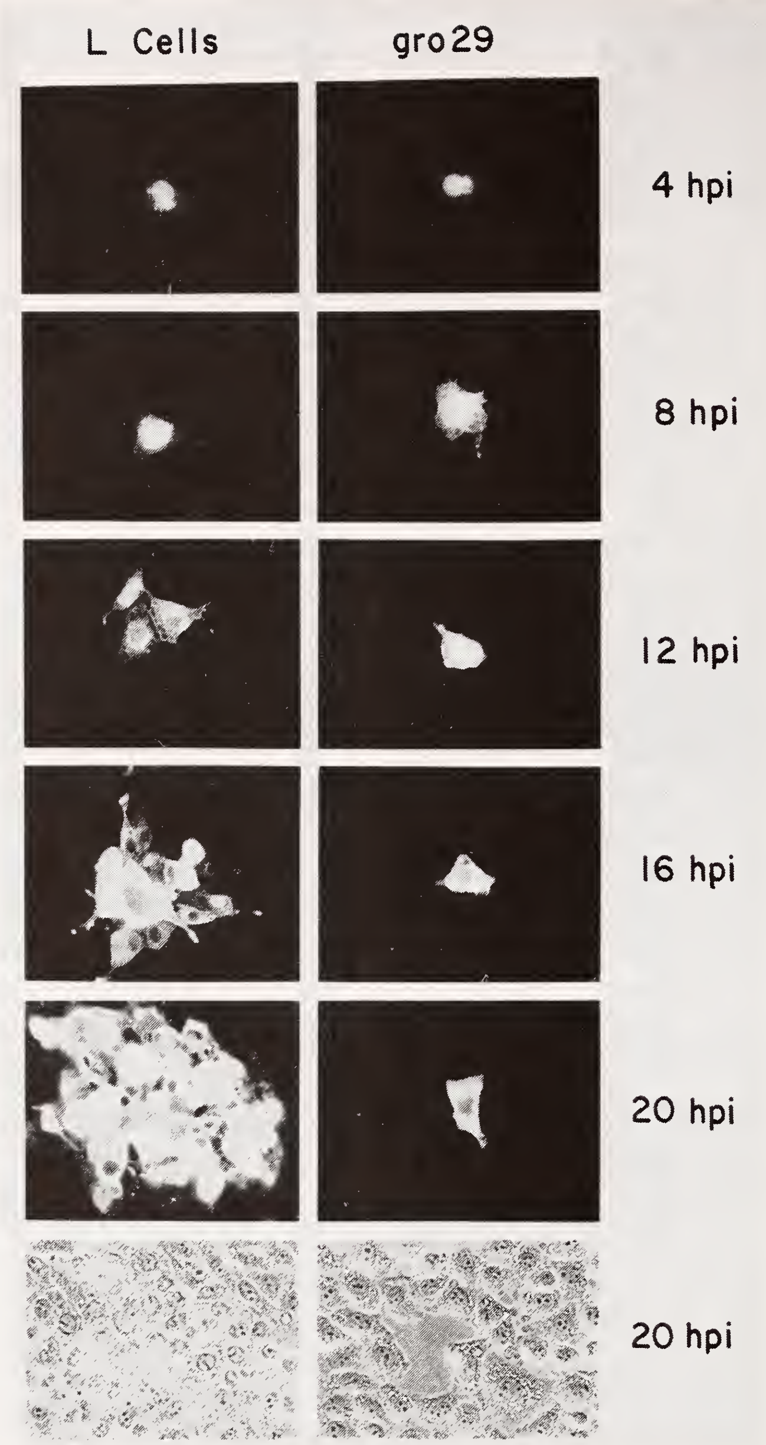


Fig. 4. Photographs at right compare parental mouse L cells (left column) and mutant mouse cells resistant to herpes simplex virus (right column) isolated by Embryology staff member Steven McKnight and colleagues. Both cells were grown on glass cover slips and exposed to low concentrations of virus. At successive intervals after infection, cells were fixed, permeabilized, and tested for the presence of viral antigens. Photos show that antigens were produced in both cell lines throughout the initial infectious cycle. At the time when the parental mouse L cells begin to shed infectious virus (12 hours after infection), however, the mutant cell line restricts infection to a single cell. These observations suggest that the defect in this host cell mutant blocks herpes simplex virus at a late step during the viral infectious cycle. Further evidence, collected by postdoctoral fellow Frank Tufaro and staff associate Martin Snider, suggests that the defect lies in the transport of glycoprotein through the Golgi apparatus.

biologists to isolate, clone, and sequence genes. A typical analysis may employ restriction enzymes to cut large DNA sequences into smaller, more-manageable fragments, which can subsequently be size fractionated by gel electrophoresis. (Gel electrophoresis, perhaps the most common tool in molecular biology, separates electrically charged molecules according to their weights by running them through a gel-like matrix; small DNA molecules move faster than large molecules, since they interact with the matrix less frequently.)

Gel electrophoresis is ideal for separating small molecules, but

for very large molecules, resolution is poor. David Schwartz reasoned several years ago that the major cause for this failure stemmed from severe distortion of the large DNA molecules. The molecules are pulled by an electrical field through holes in the gel matrix. These holes may be 100 times smaller than the molecules themselves. To get through, they must dramatically distort into long cylindrical conformations that look somewhat like writhing snakes.

To take advantage of distortion, Schwartz found that he could apply across the gel an electrical field and change its orientation so that the snake would be constantly changing direction at all times. This made it possible selectively to attenuate velocity of different molecular size ranges. Thus, snake length, related to size, became the guide for the degree of orientation of the gel electrical field, and it became possible to resolve very large DNA molecules. Schwartz has used the new technique, called pulsed electrophoresis, to separate yeast chromosomes, converting the process of gene mapping (assigning a gene to a particular chromosomal loci) to an overnight procedure instead of one taking weeks. He has also used it to separate the chromosomes of the trypanosome, a vicious unicellular parasite that causes sleeping sickness in humans. His work has allowed some of the first genetics to be established for this organism.

Pulsed electrophoresis helps researchers bridge the gap between cytogenetics, the study of gross physical chromosome structure, and recombinant DNA technology. Many biological questions fall in this gap, since their solution can be most easily accomplished by working with very large DNA molecules. An example is finding genes for human genetic diseases, such as Huntington's disease, in the midst of some six feet of DNA.

Schwartz and colleagues are themselves beginning experiments with human DNA, using yeast as a cloning system for molecules up to 2000 kilobases (two million base pairs) in length. The largest DNA fragment that can be cloned using current techniques is about 40 kilobases. Schwartz has also begun collaborative experiments with fellow staff member Allan Spradling. The two have succeeded in isolating a *Drosophila* mini-chromosome, from which they soon hope to isolate the centromere. (The centromere is a chromosome structure which holds the doubled chromosome strands together during replication.) If accomplished, this will be the first centromere isolated from any higher organism. The procedure could become a standard method for isolating centromeres from the chromosomes of other organisms.

Exploring Chromosome Structure and Function. In what ways does activity of chromosomes affect development of an embryo? This is the question that fascinates Joseph Gall, who has been studying chromosome structure and function for many years. For

his model system he has chosen the extraordinarily large "lampbrush" chromosomes found in the oocytes (maturing eggs before fertilization) of certain amphibians; the products of these chromosomes control all events in the early stages of embryo development. Because these chromosomes are so large and because so many of their genes appear to be turned on (as reflected in hundreds of looped-out sites of active RNA synthesis), lampbrush chromosomes permit a variety of molecular and microscopical studies that cannot be done in any other organism.

During the report year, Gall continued his efforts to determine exactly what sequences of newt lampbrush DNA are transcribed on a particular cluster of loops. To do so, he and his colleagues use a technique called *in situ* nucleic acid hybridization, in which radioactively labeled RNA or DNA probes, made in the test tube, are used to locate complementary RNA molecules made by the oocyte along the chromosomes. Earlier, Gall and colleagues found that the loops synthesize not only messenger RNA, as expected, but also many other sequences including a long stretch transcribed from simple, highly repetitive satellite DNA. This result was unexpected, since the poorly understood satellite DNA is not normally transcribed. This year, Gall and postdoctoral fellow Lloyd Epstein report a second instance of satellite DNA transcription in newt lampbrush DNA; the RNA transcript molecule in this case has either the same length as the DNA from which it is transcribed or integral multiples of that length. They find that a synthetic dimer RNA molecule transcribed from this satellite DNA sequence spontaneously cleaves into the monomer form; that is, under certain ionic conditions, the molecule cleaves without the help of an enzyme. Such "self-cleavage" is an unusual chemical reaction, and Gall is hopeful that further study will provide hints as to the role of satellite RNA in the developing cell.

With postdoctoral fellows Mark Roth and Patrick DiMario, Gall is also attempting to identify and characterize some of the most important proteins associated with lampbrush RNA transcripts in the newt and frog. (Frog chromosomes are smaller and more difficult to work with than those of the newt, but they are better suited to gene cloning and other molecular studies.) To isolate individual proteins, Gall *et al.* make monoclonal antibodies against a large number of nuclear proteins. They then select those antibodies that bind specifically to the lampbrush chromosomes. In this way, they hope to identify proteins involved in the synthesis, processing, and packaging of the RNA transcripts, and possibly in the transport of the messenger RNA to the cytoplasm of the egg. So far, they have identified several dozen antibodies of potential interest in the newt. Some of these bind to nearly all loops on the chromosomes, whereas others bind to only one pair of loops or to a small number of loops.

In a different vein, Gall and colleagues during the report year

completed two projects dealing with the ends, or telomeres, of chromosomes. Telomeres pose unique problems during chromosome replication. Graduate student Rahul Warrior found that the nucleotide sequence at the end of a small linear molecule in the mitochondria of the freshwater *Hydra* differs from other previously studied telomeres. Celeste Berg, also a graduate student, found that a linear molecule from the protozoan *Tetrahymena* failed to replicate correctly when injected into frog eggs, despite the fact that it contains normal telomere sequences. These results suggest to Gall that the problem of telomere replication may have been solved in different ways by different organisms.

The Changeable Genome

> DNA sequence changes (substitutions, insertions, deletions, and rearrangements) are the likely source of phenotypic variation in evolution since they can affect genes or their regulation and influence biochemistry, development, morphology, and behavior.
>
> Roy J. Britten
> *Science 231*, p. 1393, 1986

Techniques of molecular biology are ever improving, allowing increasingly more detailed study of chromosomes and genes at developmental time scales. But they are also proving useful as a means of studying changes that genomes undergo over a much longer, evolutionary time scale. For as a species changes over time, so too does the organization of its genome.

Changes in genome organization are at the core of studies by Embryology staff member Nina Fedoroff and Carnegie-Caltech researcher Roy Britten. Fedoroff concentrates on the molecular characterization of movable pieces of chromosomes called transposable elements, which can promote drastic reorganization of the genome. Britten, meanwhile, studies how genome changes—by transposable elements and other means—may affect evolution.

Maize Transposable Elements. Forty years ago, the geneticist Barbara McClintock discovered that transposable elements may have profound effect on genetic expression. Transposable elements have since been found in dozens of organisms, but they remain poorly understood. Do they perform roles in regulating genes or in facilitating adaptation or speciation—or are they mere parasites of the genome? Partly to answer this question, Nina Fedoroff in 1978 launched a program to study maize transposable elements at the molecular level. Aided by the enormous stock of genetic information gathered earlier by McClintock, she and her colleagues have identified and characterized the simplest family of maize transposable elements—the *Ac-Ds* family. Last year, they began to examine the more complex *Spm* family.

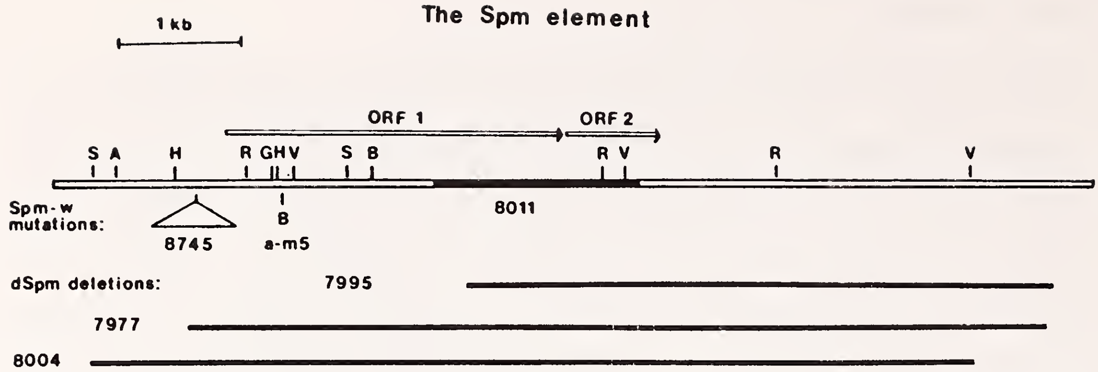


Fig. 5. Diagram of an intact maize suppressor-mutator element (*Spm*-s-7991A) and several defective derivatives, isolated by Nina Fedoroff and her Department of Embryology colleagues. The two large protein-encoding, or open-reading (ORFs), frames in the intact *Spm* element are indicated by arrows. The mutations detected in *Spm*-w-mutations (8745, a-m5, and 8011) are represented in the line immediately below the intact element (with the deletion in the 8011 element indicated by the solid line), while the deletions in the three defective copies at bottom (7995, 7977, and 8004) are indicated by solid bars below the diagram. Fedoroff *et al.* find that elements having mutations in their left halves (8745, a-m5, and 8011) are able to transpose on their own, while 7995, having a deletion from its right side, cannot. (7995, 7997, and 8004 can transpose only when an intact *Spm* element is present elsewhere in the plant's genome.) This suggests that the protein required for transposition (transposase) is encoded by the element's right half. However, sequences in the left half appear to be necessary for maximal expression of the transposase, since 8745, a-m5, and 8011 do not produce normal amounts.

When the *Spm* element transposes, it can activate or inhibit the expression of genes into which it inserts. By studying fully functional *Spm* elements as well as several types of mutant *Spm* elements, including one that shows attentuated function and one completely devoid of function, Fedoroff and the members of her lab have determined the nucleotide sequences of *Spm* and studied which sequences of coding *Spm* DNA are critical for normal function. One of those sequences, occupying most of the element's right half, appears to encode the element's transposase, a protein that is required for *Spm* transposition. Another sequence encodes a 1.1-kilobase transcript, at least part of which is encoded at the extreme left of the element. Sequences in the left half seem to be necessary for maximal expression of the transposase sequence, since mutations therein reduce levels of transposase (see Fig. 5).

The transposase appears to bind to a 12–base pair sequence found in several copies in both a direct and an inverted order at each end of the *Spm* element. Fedoroff *et al.* hypothesize that there is a transposable element–encoded protein, probably transposase, which has the ability to bind to the repeated sequences to promote gene expression and transcription of transposable element–encoded proteins. Future experiments will concentrate on the functional analysis of *Spm* by in vitro mutagenesis. (In vitro mutagenesis is a technique enabling researchers to study inside a

living cell the effect of an artificially altered, or mutated, sequence of DNA.)

Such analysis has already begun in Fedoroff's lab for the *Ac* and *Ds* elements. The group completed a study during the report year in which the *Ac* element was introduced (via a bacterial vector) into the cells of the tobacco plant. The experiment was designed to determine whether the element would function in tobacco, a dicotyledonous plant, as it normally does in the monocotyledonous maize plants from which it was isolated. They found that not only does the *Ac* element function as well in its new milieu as it does in maize, it has a surprisingly high transposition frequency. The reasons for this are yet unclear.

In related experiments, Fedoroff and colleagues are also engaged in attempts to transfer *Ac* into *Arabidopsis*, a plant with an extremely small genome, for the purpose of evaluating its usefulness in this plant as a mutagen and gene tag. Already they have begun to construct mutated *Ac* elements for in vitro studies of *Ac* function.

Genome Evolution. Roy Britten believes that transposable elements play important evolutionary roles. He also believes they are closely related to the many thousands of noncoding DNA sequences that exist in the genomes of higher organisms. (Britten, who works today at Caltech's Kerckhoff Marine Laboratory, discovered these repeated sequences more than twenty years ago as a staff member at Carnegie's Department of Terrestrial Magnetism.)

Britten does both experimental and theoretical studies of genome evolution. In his experiments, he uses techniques of DNA hybridization to compare relationships of repeated sequences among closely related species. In this way, he hopes to determine if, and at what rate, these sequences could have been transferred between species. This, in turn, would provide insight into rates and mechanisms of evolution.

During the report year, he examined a long repeated sequence family cloned from the DNA of the sea urchin *Strongylocentrotus purpuratus*. One of the 3-kilobase-long subfamilies from this repeat, he found, was also present (in an exact copy) in another, very distantly related sea urchin species (*Tripneustes gratilla*), whose single-copy DNA diverges widely from that of *S. purpuratus*. It is highly unlikely, says Britten, that this 3-kb-long segment was present in both lineages before they diverged (more than 100 million years ago), especially considering that most of the genomes of these organisms differ enormously. More likely, he says, is that the repeats were recently transferred between the species—either by the natural action of transposable elements or by a viral infection.

Britten is also using the literature to review measurements of

single-copy, non-gene-coding DNA evolution in various species. Last year, he reported that the single-copy rate of mutation appears to differ significantly between species, and that the mutation rate for single-copy DNA is much higher than the mutation rate for the genes (which presumably are conserved because of selection pressures in the encoded proteins). This year, by comparing relationships between hybridization and divergence in literally thousands of species pairs, he finds that different parts of the single-copy sequences in different species evolve at different rates: a few fragments of DNA in each show a much greater degree of divergence than the majority. He does not yet know why this should be.

Gene Function: Studies at the Department of Embryology

An organism's genome contains a great mass of DNA, much of which serves no known purpose. The genome also contains a great many proteins, which in many cases are essential to the proper functioning of the genes. As Carnegie scientists continue to examine how genes are turned on and off during development, they pay more and more attention to these proteins, using techniques that allow them to explore genes in their natural environments—either in vivo, within the organism, or in vitro, in a test tube assay that mimics the natural environment. At the Department of Embryology, Steven McKnight, Sondra Lazarowitz, Donald Brown, Allan Spradling, and Samuel Ward have developed different experimental systems, but each investigator is asking the same general question: how does a gene work?

Interactions of Viruses with the Animal Cell Genetic Apparatus. The goal of staff member Steven McKnight is to understand how viruses exploit the genetic apparatus of the animal cells they infect. The collaborative study described previously (p. 25)—the isolation of mutant cell lines that cannot support viral infection—is one of several approaches used in his laboratory to identify components in the host cell that are critical for viral growth.

Over the last several years, McKnight and colleagues have relied heavily on techniques of in vitro mutagenesis to determine which DNA sequences in viruses are responsible for regulating viral gene expression. They systematically mutate various viral DNA sequences, introduce the mutated sequences into host animal cells, and then correlate the phenotypic effects of the mutations with the original locations of the sequences within the viral chromosome. From this they can identify exactly which viral DNA sequences are involved in regulating viral gene expression. They have shown that, in certain cases, these sequences serve as binding sites for regulatory proteins that are encoded either by the virus itself or by the host cell.

During the report year, with colleagues Peter Johnson, Barbara Graves, and Bill Landschulz, McKnight made considerable progress in identifying and characterizing one such protein encoded by the host cell. This protein binds at several locations within the long terminal repeat segment of the murine sarcoma virus (MSV) genome. Last year, the group found that one of the binding sites in MSV plays a critical role in the expression of viral RNA. This site contains a nucleotide sequence reading CCAAT (C represents the nucleotide cytosine, A adenine, T thymine); such a "CAT" sequence, McKnight notes, is common to many mRNA-coding genes in the host cells that MSV typically infects.

This year, the group has begun to identify the polypeptide that accounts for CAT-binding activity. Once this is accomplished, they hope to purify sufficient quantities to obtain either a partial amino acid sequence of the polypeptide, or to immunize rabbits. The next step will be to find and clone the host cell gene that encodes the protein. Then, they can begin functional studies of this gene's role in the synthesis of viral mRNA.

The task that McKnight has initiated is not an easy one. The relationship of a virus to a host cell is complex. So, too, is the action of the virus itself. Herpes simplex virus (HSV), another animal virus studied by the McKnight laboratory, initiates a three-tiered program of viral gene expression when introduced into cultured animal cells. This year, the McKnight group confirmed that the program is cyclic: that is, a gene product of the third stage is required to initiate the first stage during the subsequent infectious cycle. Postdoctoral fellow Steve Triezenburg has identified and sequenced the gene encoding the third-stage viral factor, called the "virion factor." He has also studied one of the first-stage genes whose activity it induces. Yet unanswered is whether the virion factor binds directly to the first-stage gene or whether there is an intermediary binding protein.

Though the gene products inducing the second and third stages of HSV infection have not been fully characterized, McKnight, graduate student Steve Weinheimer, and collaborator Donald Coen of Harvard Medical School have found, contrary to prevailing assumptions, that these products do not activate stages two and three by binding directly to the viral genes; rather, they appear to modify or interact with intermediary DNA-binding proteins from the host cell itself. Again, as with MSV, a mammalian host cell appears to participate actively in the expression of its viral parasite.

The Molecular Characterization of Geminiviruses. Like McKnight, staff associate Sondra Lazarowitz studies viruses with the hope of understanding mechanisms of gene expression in host cells. The viruses she studies, called geminiviruses, infect plants.

Lazarowitz reported last year that the four separate DNA components she found in extracts from squash infected with the

whitefly-transmitted Squash Leaf Curl Virus (SqLCV) were in fact components of two different but closely related bipartite geminiviruses—one with a narrow host range of infection (SqLCV-NR), the other with an unexpectedly broader range (SqLCV-BR).

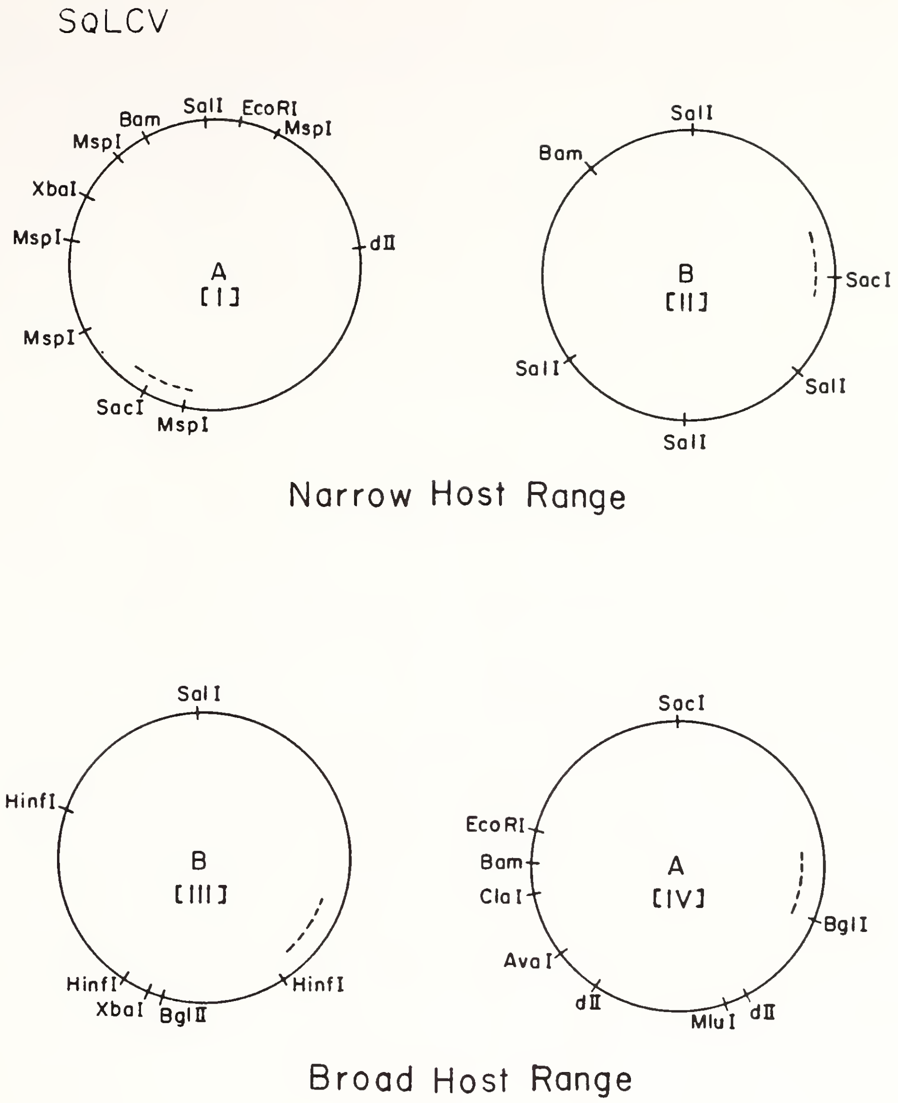
This year, using molecular hybridization and sequencing techniques, Lazarowitz, with Allison Pinder and graduate student Inara Lazdins, probed in detail the common regions of the bipartite components. (A small sequence element is common to this region in all geminiviruses; by locating this sequence element, Lazarowitz and colleagues could identify the common regions for each bipartite pair.) (See Fig. 6.) They found that these common regions, though not completely identical, were highly similar in the two SqLCV's. Most significant was the finding that SqLCV-NR has a deletion of thirteen bases compared to SqLCV-BR. This, plus the similarity in sequences of the genes flanking these regions, led her to the conclusion that the two SqLCV's are closely related in terms of their evolution.

This relationship could have begun, she explains, by a mutation in the common region of one component of one bipartite virus, followed by recombination between the common regions of components under selective pressure in the appropriate host to generate the other bipartite virus with an altered host range. She suggests that the common regions in geminiviruses may determine the host range characteristics of each. Thus, it is here that she will concentrate her efforts in looking for transcription and replication control regions that interact with host cell regulatory factors.

Regulation of Chorion Genes. In seeking other insights into gene regulation, staff member Allan Spradling uses as a model system the amplification (rapid increase in number) of chorion, or eggshell, genes of *Drosophila*, which are found in two major clusters on the X and third chromosomes. Spradling has long been intrigued by the chorion gene system because only one copy of the sequences comprising the chorion gene clusters exists in the germ line. Chromosome replication can be studied in greater detail in *Drosophila*, using the chorion gene system, than it can in virtually any other eukaryotic organism.

Spradling has developed a powerful in vitro mutagenesis approach to explore how chorion genes are replicated and regulated. It is similar in intent to the one employed by McKnight, but it operates quite differently. The mutated chorion genes are not inserted into cells directly; they are instead inserted as passengers on naturally movable transposable elements. Three years ago, Spradling and former staff member Gerald Rubin found they could piggyback genes onto the "P" transposable elements of *Drosophila*. Once inserted into a female fly's egg cell, both the transposable element and the gene it carried were incorporated into the germ line. It

a



b

HOMOLOGY REGIONS OF SqLCV II (NARROW HOST RANGE, B COMPONENT) AND IV (BROAD HOST RANGE, A COMPONENT)

```
              10        20        30        40        50        60        70        80        90       100       110
II   AACGAAGTGAGTTAGGGTTTCAGTGGCATATTTGGTAAATATGAACCGGGACACCAGGGGGAGCTCTCTCTAAAACCTATTATTGCTGGTGTCCTGGTGTCCCATTTATAC
IV   AACGAAAGGAATTAGGGTTTC GTGGCATATTTCGTAAATATGCATCGGG CACCAGGAGGTGTCCTCTCAACTTTCTCATATTGCTGGTGTCCTGGTGTCCTATATATAC
              10        20         30        40         50        60        70       80        90       100
                                    (59)                                                  (29)

                          120       130        140       150       160       170       180       190       200       210
II      AA  CTC T     C TGGGGAGGACACCA GGGGCAAAATCGGCCATCCGCAATAATATTACCGGATGGCCGCAAATTTTTTGGTGTCCT  ACTTTT ACAA GGCCCAGTCCCA
IV   CTCAAGACACATAAAGCCTCTAGGGGACACCAAGGGGCAAAATCGGCCATCCGCAATAATATTACCGGATGGCCGCCCGTTTTT GGTGTCCTCTACTTTAGCCCACGGGGCAGGCCCA
    110       120       130       140       150       160       170       180       190       200       210       220
                                                          (64)                                         (16)
```

Fig. 6. Diagram (a) represents the bipartite genomes of the narrow and broad host range Squash Leaf Curl Viruses (SqLCVs), as analyzed by Department of Embryology staff associate Sondra Lazarowitz and colleagues. The locations of the common regions are indicated by dashed lines. (Slashes in circles show restriction enzyme sites.) In (b), DNA sequences of the four common regions are compared; regions showing extensive homology are underlined. Numbers in parentheses indicate the number of identical bases in each. The results provide evidence that the two SqLCVs are closely related.

was the first time functional genes had been inserted into a higher organism.

With this technique, Spradling and colleagues hope to identify genes and gene products required for the rapid amplification of chorion genes, and to learn how the DNA sequences involved may control overall replication. (Replication is the duplication of all of the DNA in the genome; amplification is the multiple copying of only small parts of that DNA.) Spradling *et al.* have gradually narrowed their search to smaller and smaller DNA regions in the chorion gene clusters apparently responsible for amplification. They have found, for example, that each gene cluster contains only a single 300-nucleotide-long region essential for amplification within the region of 12,000–15,000 nucleotides undergoing replication. This critical region is likely to include a specific origin (start site) of replication, as well as sequences involved in developmental control. Further, the critical region appears to overlap sequences required for chorion gene transcription. Spradling thus suggests that a common mechanism may regulate the tissue-specificity of both amplification and transcription.

Further insight is expected from study of the gene products required for chorion gene amplification. Postdoctoral fellow Richard Kelley has identified two genes—fs(3)293 and fs(3)272—where mutations greatly reduce or eliminate amplification. One of them, 272, appears to be the best current candidate for encoding a product required specifically for amplification. The 293 gene, in contrast, encodes a product that appears to be necessary for chromosome replication (see Fig. 7).

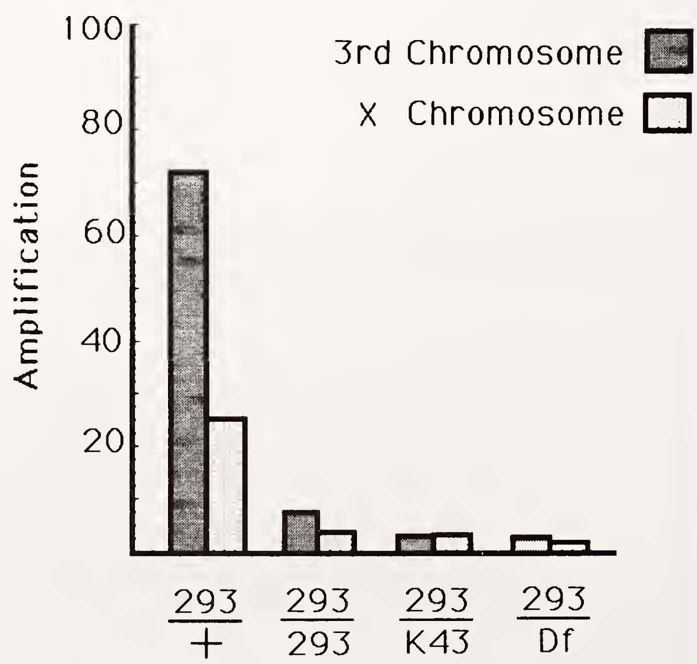


Fig. 7. Allan Spradling and colleagues at the Department of Embryology have found two *Drosophila* chorion (eggshell) genes on the third and X chromosomes where mutations greatly reduce or eliminate amplification. One of them, fs(3)293, encodes a product required in mitotic cells during larval development; larvae containing mutant alleles of the gene fail to develop. Chart above shows that DNA extracted from late-stage egg chambers in wild-type flies containing a mutant 293 (293/+) amplify normally. In those females homozygous for the mutation (293/293), and in heterozygous flies with one amplification defective allele and one null allele or a deficiency (293/K43 and 293/Df, respectively), amplification is reduced.

Meanwhile, postdoctoral fellow Lynn Cooley is developing a powerful new method to speed up the frequently arduous process of isolating *Drosophila* genes defined only by mutation. Her method involves the controlled transposition of transposable elements. When a transposable element moves into the middle of a gene's DNA sequences, its sequences physically "tag," or mark, that gene. Cooley selects fly strains containing single transpositions of elements inserted virtually at random on a known chromosome. When a mutation is detected, the gene whose disruption is responsible can be readily cloned, since it is tagged with a single transposable element found nowhere else in the mutant's genome.

The Dual 5S RNA Gene System in Xenopus. Like Spradling and McKnight, Department of Embryology director Donald Brown also explores gene function. His work, undertaken with the 5S RNA genes in the frog-like *Xenopus*, has long served as a model for studying gene function, one that is often cited in textbooks and journals.

5S RNA genes come in two varieties—oocyte-type and somatic-type. These two varieties are very similar and are present in all cells of *Xenopus*, but they are not expressed similarly. The somatic 5S RNA genes are expressed in all cells, both somatic and oocyte, but the oocyte 5S RNA genes are expressed only in oocyte cells. (Oocytes are germ, or reproductive, cells; all nongerm cells of an organism are termed somatic.) Last year, Brown and his colleagues reported that a protein factor—designated TFIIIA—controls this differential expression by two simple principles. When the concentration of TFIIIA is high in a cell, as it is in oocytes, all of the 5S RNA genes function. When its concentration drops, as it does once the egg is fertilized and embryonic development begins, only those genes that bind TFIIIA most tightly (the somatic 5S RNA genes) are active. The weaker-binding oocyte 5S RNA genes are repressed.

This year, Brown and postdoctoral fellow Kent Vrana began efforts to map the TFIIIA protein in detail. They found that it consists of discrete domains with separable functions. When sections of the protein were deleted and tested for function in vitro, Brown and Vrana found that the two ends of the protein appear to be required for transcription of, but not binding to, the 5S RNA gene; the middle section of TFIIIA is what actually binds to the 5S RNA gene. This middle region has a series of repeated zinc-binding regions ("zinc fingers") of the sort that are being found increasingly in proteins that interact with RNA and DNA. Again, as it has in the past, the 5S RNA gene system is proving its remarkable value as a system with general implications in eukaryotic biology.

Brown's group discovered last year that TFIIIA is not the only protein factor that binds to the 5S RNA genes. There are at least two others, still unidentified. The resulting transcription

complex is remarkably stable, that is, many rounds of RNA can be made from it. This is probably because the proteins bind not only to the gene but also to each other. According to Brown, this stability has essential biological consequences. It can account, for example, for the stability of the differentiated state in cells committed to make a specific product (for instance, a red blood cell), for in these cells, the same genes remain activated for long periods of time.

Postdoctoral fellow Alan Wolffe found that the transcription complex is preserved during transcription but is dislodged during DNA replication. Once the chromosomes are replicated and the cell divided, the two progeny DNA molecules must be reprogrammed, presumably from free transcription factors present in the nucleoplasm. (Brown and Wolffe detect no inheritance of a preexisting transcription complex.) This may account for the observation that a committed cell can make its product only after it has stopped dividing. The fact that "housekeeping" genes (those expressed by all cells) can continue to be expressed in dividing cells suggests that the factors that influence their expression are abundant in the cell. Thus, they can be easily reprogrammed after each cell division. Still a mystery is what distinguishes development of a committed cell. Is there perhaps a "master" gene for each cell type, Brown asks, one whose transcription complex can withstand DNA replication and pass on its epigenetic imprint to progeny genes?

Genetic Analysis of Cell Morphology. Staff member Samuel Ward approaches the problem of cell commitment from another perspective: that of cell shape. He notes that in viruses, most instructions for assembly are contained in the shapes of the proteins themselves: the molecules come together chemically much as atoms do, to form crystals. Is this true also for cells, he asks? If not, what other sources of information are used by the cell to control cellular assembly during development?

Ward's lab has for many years used as a model system the single-celled sperm of the roundworm *Caenorhabditis elegans. C. elegans* is ideal for laboratory culture and genetic analysis, and its sperm are differentiated cells which can be isolated and studied almost as if they were single-celled organisms. Ward reports this year that he, his colleagues at the Department, and collaborators in England and Texas have so far found, using molecular cloning techniques, 41 genes that encode the major sperm protein. About half of these genes appear to be evolutionary relics of defective gene duplications, but the other half appear to be functional genes each encoding a nearly identical protein. These proteins are assembled into filaments that form the internal cytoskeleton of the sperm pseudopod. (A nematode sperm crawls like an amoeba; hence it has a pseudopod and not a flagellum.) The worm needs many genes because its sperm develop in a very short amount of time.

Department of Embryology staff, June 1986. Bottom row, left to right: Kent Vrana, Ellen Cammon, Joseph Gall, Earl Potts, Donald Brown, David Schwartz, Karen Bennett, Ronald Millar. Second row: Richard Grill (kneeling), Diane Shakes, Nicole Angelier, Celeste Berg, Barbara Sosnowski, Diane Thompson, Cindy Smith, David Meloni, Christine Murphy, Nina Fedoroff, Joe Vokroy. Third row (standing): Inara Lazdins, Ernestine Flemmings, Robert Kingsbury, Allison Pinder, Martyn Darby, Peter Johnson, Terry Orr-Weaver, Alan Wolffe, Patrick DiMario, Richard Kelly, Lynn Cooley, Samuel Ward, Steven McKnight, Sondra Lazarowitz, Steven Weinheimer, Eileen Hogan, Gene Leys. Fourth row: Matthew Andrews, Ophelia Rogers, Mark Roth, William Landschulz, Frank Tufaro, Riccardo Losa, Patrick Masson, Martin Snider, Michael Koval, Shirley Whitaker, Susan Satchell, Patricia Englar.

Members of Ward's lab have found that 36 of the 41 genes are grouped into seven clusters of genes, each of which consists of from three to seven genes. Further, the clusters are themselves clustered on the chromosomes: four clusters are on the left side of chromosome II, and three are in the middle of chromosome IV. Ward hopes to be able to determine if this clustering, like that studied in *Drosophila* by Allan Spradling, has functional significance, perhaps ensuring that genes all expressed at the same time in the same cell can be switched on together.

Meanwhile, using the conventional genetic approach, postdoctoral fellow Steven L'Hernault has continued his effort to identify new genes that affect sperm motility. Laboring over agar plates, he cultivates large numbers of worms, selecting mutant strains that are sterile (i.e., that have defective sperm). So far, he has identified a total of 30 genes necessary for normal sperm differentiation. He has also obtained several rare mutations that suppress the sperm defects in one of those genes. The mutations, it turns out, are in other genes.

Do the products of these other genes interact with the products of the defective gene to correct the defect, or do the mutated genes take over the function of the defective gene by following the same pathway of differentiation? Once the molecular identities of the genes are established, it should be possible to answer this question. Ultimately, writes Ward, the synthesis of molecular and genetic techniques will help him and his colleagues unravel the mechanism of sperm assembly, and provide clues as to how cells differentiate.

Plant Development and the Effect of Light

> As information at various levels accumulates, it should become increasingly feasible to unravel the fundamental processes underlying light regulation of greening.
>
> Winslow R. Briggs
> July 1986

As we have seen, a major thrust in the molecular work of the biologists at the Department of Embryology is to understand how genes function during development. Increasingly, this is becoming a major goal of scientists at the Department of Plant Biology—to understand how genes turn on and off during plant development.

In studying the regulation of plant genes, plant scientists confront an environmental variable that is missing in animal biology—the effect of light. At the Department of Plant Biology, William Thompson has continued to probe the role of light in the regulation of pea and wheat genes. This year, both he and Winslow Briggs (in experiments undertaken at the molecular and physiological levels) report significant progress in understanding how phytochrome, a light-receptor pigment, induces the onset of photosynthesis. Meanwhile, Arthur Grossman continues to study the genes of a unique algal light-harvesting system. This year, he reports preliminary in vitro mutagenesis experiments designed to study function.

Phytochrome and Development. Phytochrome is an important pigment. It plays roles in many developmental processes, such as greening (activation of photosynthesis), flowering, and seed germination. Phytochrome exists in two forms. Before a seedling has seen light, for example while it is still beneath the soil's surface, its phytochrome (if present) exists in an inactive form. Once it is exposed to very tiny amounts of red light, however, this inactive form, called Pr, is converted to its active, or Pfr, form. Even minute amounts of Pfr may be enough to activate important developmental changes. The reverse transition—from active to inactive forms of phytochrome—can be effected by exposing a plant to far red light. (This may occur naturally, for instance under a

canopy of vegetation in which chlorophyll has absorbed virtually all of the red light and little of the far red light.)

Over the past few years, Thompson and research associate Lon Kaufman have studied how light induces changes in the mRNA products of thirteen different photosynthesis-related genes. These genes, three of which have so far been identified (one this year by postdoctoral fellow Michael Dobres), respond to light in extraordinarily diverse ways (see *Year Book 84*, p. 19). Despite this diversity, Thompson *et al.* find that, in most cases, the effects are regulated by a single pigment—phytochrome.

During the report year, the investigators have continued to study these phytochrome-induced responses. They have examined, for example, the rate at which each of the inductive responses "escapes" from phytochrome control by exposure at various times to far red light. The escape rate, they find, differs for each response. Because of this, Thompson believes that different phytochrome-regulated genes have different signal-response chains. Presumably, therefore, the responses of different genes can be "coupled" to the phytochrome system in different ways.

However those signal-response chains may work, it is clear that the program of greening induced by red light is very complex. This complexity belies the fairly simplistic model (derived from the substantial literature of phytochrome-mediated changes related to greening) stating that phytochrome, as Pfr, induces greening merely by turning on specific photosynthesis-related genes. Especially critical in that model seems to be the transcription of a gene encoding a chlorophyll-binding protein.

Though the model is correct, recent work suggests that Pfr may regulate greening, as well as other processes, on more than the transcription level. During the report year, for example, Benjamin Horwitz, a visiting investigator in the Briggs lab, obtained preliminary evidence that the phytochrome-mediated synthesis of chlorophyll itself, and not of a protein that binds to it, may be the limiting step in greening. Two other experiments undertaken this year, both in the Thompson lab, suggest that phytochrome plays regulatory roles in at least one way. Lon Kaufman has found that some phytochrome-induced increases in mRNA abundance require the continuous presence of Pfr, suggesting that phytochrome may play a regulatory role at the level of mRNA stability.

Phytochrome and Gravity. Another study on phytochrome, undertaken in the Briggs lab on the gravitational response of corn roots, sheds additional insight on phytochrome's role in development. Workers in the Briggs lab had previously determined that the formation of Pfr in corn roots actually changes the gravitational response of the root. When grown in complete darkness, the roots grow horizontally, roughly at right angle to the gravitational vector; when exposed to red light, however, Pfr causes the roots to

begin growing downward—at an angle that seems to be genetically fixed. Briggs's group also found that some phytochrome-triggered gravitational responses are caused by minute amounts of Pfr, while others may require several orders of magnitude more.

Chloroplast Transcription. The effort to understand DNA organization and transcription in the chloroplast (the site of photosynthesis) in the pea plant has been under way for several years in the Thompson lab. (Pea is a particularly good plant for genetic and molecular analysis because of its longtime experimental use.) Significant progress has been made, and while there is still much to learn, the project is nearing completion. Thompson and postdoctoral fellow Neal Woodbury have been able to establish several properties of the system. First, they found that at least two-thirds of pea chloroplast DNA is transcribed. This was not unexpected, since the 120-kb chloroplast pea genome codes for over thirty known proteins in addition to all the ribosomal RNAs and possibly all the transfer RNAs required for the chloroplast translational apparatus. The investigators note, in fact, that most likely an even larger fraction is transcribed but in abundances too low to be detected.

Thompson and Woodbury found also that there are in the pea chloroplast genome several groups of genes that are co-transcribed. A co-transcribed gene produces, in each case, a large pre-mRNA transcript which is then processed into several smaller mRNAs. In some cases, the proteins derived from translation of these smaller mRNAs serve a related function, for example as different subunits of the same protein complex.

The two investigators also found that a single DNA fragment may be transcribed in such a way as to produce a variety of different-sized mRNAs. It is not clear whether these RNAs result from different starting and stopping sites in the DNA or whether they arise post-transcriptionally by some processing mechanism. Finally, the investigators found that though most transcripts are most abundant under continuous light, a few are most prominent after a brief pulse of light. These latter RNAs, writes Briggs, are prime candidates for a study of photoregulation of gene expression in the chloroplast that would parallel the extensive studies on the nuclear genome conducted in the Thompson lab.

The Phycobilisome Genes. Arthur Grossman has taken a different approach in studying how genes respond to light. He focuses on a unique light-harvesting system (the phycobilisome system) in red algae and in primitive cyanobacteria. Phycobilisomes in many cyanobacteria show a remarkable ability to adjust their components in response to whatever wavelength, or color, of light they receive. This is called complementary chromatic adaptation.

As a first step in understanding how chromatic adaptation works

at the molecular level, Grossman and colleagues have been concentrating on isolating and analyzing those genes that make up the phycobilisome units in the cyanobacteria *Fremyella diplosiphon.* The phycobilisome genes code for the pigment-proteins phycocyanin, phycoerythrin, and allophycocyanin, as well as for the colorless "linker" proteins that hold the individual units together. Grossman *et al.* have found that some of the *F. diplosiphon* phycobilisome genes, for example one of the two phycocyanin genes, are constitutive (i.e., the rate of their transcription is relatively independent of environmental factors), while others (like the other phycocyanin gene and the phycoerythrin gene) are induced by appropriate wavelengths of light.

In the case of phycocyanin (PC) genes, Grossman and colleagues find that whereas the constitutive gene set is expressed in both red and green light, the inducible gene set is expressed only in red light. (Each set consists of two genes—termed α and β.) Last year, the group reported that the genes in the inducible gene set are linked and are transcribed simultaneously as two mRNAs, one 3.8 kilobases in length, the other 1.6 kilobases. This year, they report that the larger transcript also contains instructions for making two red-light-induced linker proteins, which are required for the PC subunits to assemble onto the phycobilisome. They have so far sequenced one of these linker genes; the other is two-thirds complete. (See Fig. 8.) From these results, Grossman concludes that the

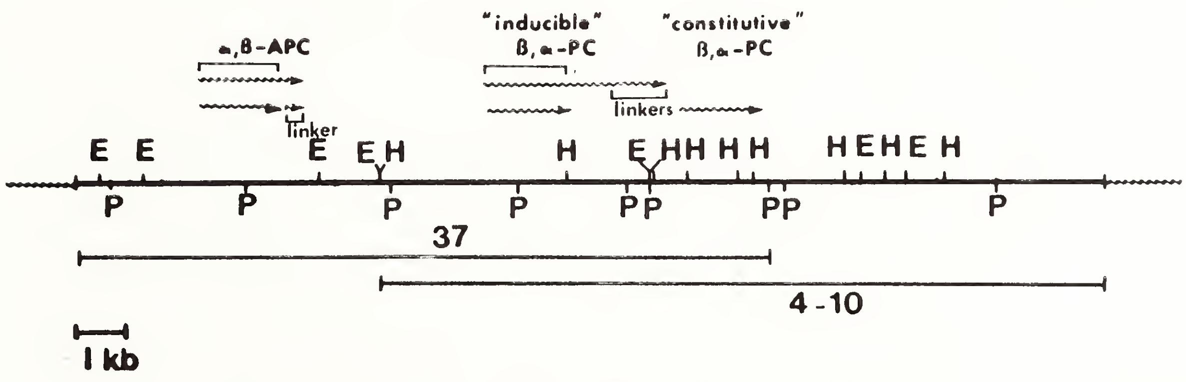


Fig. 8. Map of the genomic DNA of the cyanobacteria *Fremyella diplosiphon* made by Arthur Grossman and his colleagues at the Department of Plant Biology shows clustering of the genes for the light-harvesting proteins phycocyanin (PC), allophycocyanin (APC), and the colorless proteins (linkers), which link the proteins together into a functional unit called the phycobilisome. The genes, each of which consist of an α and β component, are read in the direction of the arrows; the size of the transcripts they produce is reflected in the arrow's length. As shown, the inducible PC gene set (which is transcribed only in red light) produces two transcripts, one of which also contains the product from the PC linker genes. The reason why there are two transcripts is not understood. The APC gene set also appears to be co-transcribed, but some evidence suggests that the larger transcript is made first and is then processed into two smaller ones. The lengths of the two clones (37 and 4-10) from which the map was derived are indicated by solid bars below; the length 1 kb indicates the relative length of 1,000 base pairs. *H*, *P*, and *E* represent the sites at which the restriction enzymes HindIII, Pst1, and EcoR1 cleave the DNA.

larger transcript most likely encodes all of the components required for structural modifications of the phycobilisome in red light. A question remains: what purpose does the smaller transcript serve?

Similar experiments are underway to isolate and study the genes of the other proteins in the phycobilisome complex. So far, Grossman and colleagues have found that the allophycocyanin (APC) genes are clustered near those of phycocyanin, but the phycoerythrin (PE) genes are not. Furthermore, the PE linker genes seem not to be contiguous with the PE α and β genes. Apparently, the PE linker genes, unlike those of PC and APC, are controlled by their own promoters.

Grossman *et al.* have reached a point in their understanding of the phycobilisome complex such that they are beginning to develop procedures for studying function. These procedures include gene transfer into *F. diplosiphon* via conjugation and transformation. Eventually, the group hopes to use techniques of in vitro mutagenesis, where the genes are mutated before they are transferred, and are tested for function by examining the resulting genetic effects on the organism.

Algae as Model Systems. These planned experiments and others like them, at Carnegie's Department of Plant Biology and elsewhere, show great promise in understanding how light actually regulates the DNA sequences of the phycobilisome system. They also promise to illuminate our understanding of how light, in general, affects genes. As Winslow Briggs writes, "One can hardly overestimate the power of integrating studies of algae with investigations of regulatory and developmental mechanisms in higher plants." Algae are much easier to manipulate than are higher plants. One can do gene-for-gene replacements in algae, or introduce into their genomes specific genes or other DNA sequences that are modified in some way. Thus, one can begin to ask which DNA sequences are required for light regulation, or which are the important structural regions of the proteins thus produced. Though it would be naive to assume that regulatory mechanisms uncovered in algae, particularly prokaryotic algae, are closely similar to those in higher plants, studies with algae will surely provide strong leads of great value.

The Human Embryo Collection

Since 1975, the Department of Embryology's human and primate embryo collection has been located at the Primate Research Center, Davis, California 95616. Professor Ronan O'Rahilly maintains an active research program using the collection. He also administers it for use by anatomists worldwide. O'Rahilly's current interest is the description of the embryonic nervous system during the earliest months of embryogenesis.

The Physical Sciences

> ... the deeper terrestrial questions lead out in the end into the realm of cosmology, where the studies of the geologist, astronomer, physicist and chemist blend. Geophysical study must borrow much from astronomy, but it should make an equivalent return, for the phenomena of the earth are most important factors in cosmology.
>
> Report of the Advisory Committee on Geophysics
> Carnegie Institution of Washington
> R. S. Woodward, Chairman
> September 23, 1902

There is no shortage of fundamental questions to challenge those who study the physical Earth and Universe. Basic understanding remains incomplete in countless areas of substantial dimension—the behavior of the Earth's moving plates and the mantle beneath, the fundamental mineralogical and petrological phenomena that explain the Earth's active processes, how stars are formed in gaseous clouds, how dark matter may form about early stars perhaps to evolve into planetary systems. These are questions widely recognized by scientists worldwide, and they are among those currently occupying the astronomers and the earth and planetary scientists of the Carnegie Institution.

Implicit in the diverse activities of Carnegie's physical scientists is that general observation noted at the start of this essay—that significant results are often largely attributable to the researcher's success in choosing a promising and original line of investigation. It is often a matter of identifying some critical area within some larger question—a link heretofore absent but now within reach, an aspect where new insight or discovery may unlock wider understanding.

A good illustration is in the recent work of astronomers Belva Campbell and Eric Persson of the Mount Wilson and Las Campanas Observatories (hereafter called the Observatories). These investigators are making large contributions to the understanding of star formation through their studies of young stellar objects—stars in the process of forming inside dense molecular clouds of our Galaxy. Attempting to penetrate the near-opaque regions at wavelengths including the near-infrared, Campbell and Persson this year compared the positions of the centroids of the central sources observed with optical telescopes with those observed at the radio wavelengths. The offsets at various wavelengths offered a unique method for probing the nonobservable features, including the geometry of the

inner-cloud regions of star birth and that of the circumstellar disks.

Another case in point grows from the remarkable breakthrough this year at the Geophysical Laboratory in attaining experimental static pressures of 5.5 megabars—pressures well beyond those at the Earth's center. On the one hand, the technological achievement creates innumerable possibilities for frontier investigation into the nature of planetary interiors, raising for the Laboratory's scientists exciting but difficult choices in planning future experimental programs. At the same time, the achievement vindicates past decisions at the Geophysical Laboratory—to proceed with the development of the diamond-cell equipment and technique, and systematically to acquire experimental data now indispensable for interpreting observations at the higher pressures now possible.

Very Distant Galaxies: Looking at the Earlier Universe

> It is appropriate to approach the problems of cosmology with feelings of respect for their importance, of awe for their vastness, and of exultation for the temerity of the human mind in attempting to solve them. They must be treated, however, by the detailed, critical, and dispassionate methods of the scientist.
>
> Richard C. Tolman
> *Relativity Thermodynamics and Cosmology*
> Clarendon Press, Oxford, 1934

To Ray J. Weymann, who in July 1986 assumed leadership from George Preston as the director of the Mount Wilson and Las Campanas Observatories, the words of Professor Tolman in closing his classic text on cosmology seem yet as challenging as when first written five decades ago. It is Weymann's goal that the endeavors at the Observatories in all fields of astronomy continue to reflect Tolman's words.

Both the scientist's sense of awe toward Nature noted by Tolman and the patient methods needed to understand it can be glimpsed in today's studies of very distant objects. Remarkable advances in recent years in the sensitivity of detectors used at telescopes make it possible to observe objects so far away that their light now seen was emitted billions of years ago. Astronomers are thus able to look at the Universe as it was much earlier in its evolution.

Excellent candidates for such studies are certain faint objects previously detected from their emission at radio wavelengths. An investigator keenly interested in these objects is Rogier Windhorst, a postdoctoral fellow at the Observatories. Windhorst brings to this work considerable experience in radio survey work at the Westerbork Synthesis Radio Telescope in The Netherlands and at the Very Large Array in New Mexico.

Windhorst and various collaborators work at several major

ground-based observatories. They currently report results from (1) spectroscopic observations at Las Campanas and at Kitt Peak, Arizona, (2) observations in several colors simultaneously with the Four-Shooter CCD system at Palomar, (3) observations with infrared systems at Palomar and at the U.K. Infrared Telescope, Mauna Kea, and (4) new radio observations at the Very Large Array. They are learning what kinds of galaxies populated the earlier Universe, and they are seeking to identify ancient, primordial galaxies—galaxies formed in gaseous clouds and perhaps visible in their initial bursts of star formation. In one case, their results provide insight independent of most past evidence as to the age of the present Universe—a controversial issue in cosmology today.

Identifying the Radio Sources Optically. Windhorst and others have found a marked upturn in the occurrence of distant radio sources at a certain level of brightness. There are an excessive number of very faint "microJansky" sources compared with ones at "milliJansky" levels. (A Jansky is a standard measure of radio "brightness." A microJansky source has one-millionth, a milliJansky source one-thousandth, this brightness. The brightest radio sources in the sky are hundreds of Janskys in strength.) Various models have been conceived to explain this phenomenon, but none have yet been confirmed. Windhorst, with various collaborators, has for some time worked to identify these distant radio sources optically and thereby to determine their true nature.

Windhorst and Observatories staff member Alan Dressler recently reported study of eighteen microJansky radio sources (brighter than visual apparent magnitude 21). Performing low-resolution spectroscopy with the Las Campanas Universal Extragalactic Instrument, the investigators succeeded in identifying spectroscopically all eighteen radio sources. Three proved to be stars in our own Galaxy. Three others were identified as early-type (i.e., elliptical) galaxies. The remaining twelve, Windhorst and Dressler showed, are blue galaxies having narrow but faint emission lines, whose spectra suggest ongoing bursts of star formation. Several of these galaxies are also peculiar in morphology: i.e., they were at one time merging or interacting galaxies. The redshifts are of intermediate value ($z = 0.1$–0.6).

These results disprove earlier suggestions that the galaxies accounting for the upturn in the source counts are nearby dwarf galaxies or normal spiral galaxies. Instead, the upturn is apparently accounted for by the blue, actively star-forming, sometimes merging or interacting, radio galaxies.

Windhorst and David Koo, a former postdoctoral fellow at the Department of Terrestrial Magnetism and now of the Space Telescope Science Institute, are continuing their past collaboration identifying milliJansky and microJansky radio sources. They observe with the Palomar Four-Shooter detection system, which contains four CCD

arrays capable of simultaneous deep observations of objects over a large area of sky. The instrument was adapted by James E. Gunn of Princeton University from instrumentation originally built for the Space Telescope. Installed at the 200-inch telescope, the system offers an unprecedented capability for studying very faint objects. Typically, about twenty minutes of Four-Shooter time is required for optical detection and identification of the radio sources down to visual magnitude 25. For certain sources, integrations of up to one hour have been required for detections down to the remarkably faint level of magnitude 25.8 in waveband Gunn r and 26.0 in Gunn g.

Their identifications have been going well: of one sample of 70 previously unidentified radio sources, Windhorst and Koo associated 68 with faint objects, mostly galaxies. This was an important result, because according to certain models explaining the distribution of milliJansky radio sources, this population should contain a significant number of primeval galaxies.

In earlier work, Richard Kron of the University of Chicago, with Koo and Windhorst, found that the brighter radio sources are, in general, giant elliptical galaxies, while the very faint, sub-milliJansky sources are a class of blue, often interacting or merging, galaxies. (The earlier-described Windhorst-Dressler results supported the presence of the blue galaxies.)

Investigating the dual population, Windhorst and Marc Oort from the Sterrewacht, Leiden, recently showed from observations at the Very Large Array that the two types are distinctly different in radio morphology. All the red giant ellipticals are extended radio sources, while the blue radio galaxies are essentially all compact. The question remains, whether the very faint blue galaxies are indeed primeval.

Unidentified milliJansky sources, fainter than Gunn r magnitude 26.0, could be very-high-redshift galaxies, possibly primeval. To investigate this possibility, Windhorst, with Gerry Neugebauer and Keith Matthews of Caltech, performed near-infrared photometry with the infrared systems at the Palomar 5-meter telescope, obtaining observations in the directions of the unidentified sources as well as observations of a calibration sample of somewhat brighter radio galaxies having measurable redshifts.

Accurate seven-color photometry of the calibration sample determined characteristic features of faint, red radio galaxies; such galaxies, for example, have very red colors ($r - K$ greater than 5). In the case of one of the unidentified sources, the observations yielded an upper limit in the infrared (H) of magnitude 21.2. The radio source is most likely a galaxy with a very large redshift (z greater than 2.0–2.5) and is a serious candidate to be a primeval radio galaxy. Studies of other possible candidates with deeper near-infrared photometry and Four-Shooter frames are needed.

How Old Are the Faint Radio Galaxies? Windhorst, Koo, and Hyron Spinrad (University of California, Berkeley) used the Kitt Peak 4-meter Cryogenic Camera to obtain low-resolution spectra in the red of several faint, very red radio galaxies—i.e., giant ellipticals. The reddest-occurring colors of such galaxies at a given high redshift constrain the earliest possible time of their formation. The purpose of Windhorst, Koo, and Spinrad was to determine the earliest possible formation epoch of giant ellipticals, thereby setting a lower limit to the age of the Universe.

The radio galaxies in the sample are generally double sources having very steep radio spectra. Optical spectra showed that such objects at brighter magnitudes are intrinsically luminous giant elliptical galaxies much alike in absolute magnitude. Measurements of redshift z for certain brighter galaxies fell between 0.60 and 0.85.

The data were analyzed by means of color-vs.-redshift and color-vs.-magnitude diagrams in conjunction with recent spectral evolution models for giant elliptical galaxies developed by Gustavo Bruzual (Merida, Venezuela). Figure 9 is a color-magnitude diagram showing the complete sample of galaxies, including those whose redshifts are yet unknown. The reddest-occurring color serves to constrain ages.

The diagram shows that the reddest color of a radio galaxy is about 2.4. The good match of the reddest models to the red upper boundary of the data serve to justify Bruzual's models and their assumptions. Assuming that the models are indeed valid, then, the very red radio galaxies appear to require ages of 14–15 billion years. In the case of the galaxies lacking precise redshifts (r fainter than 22), this conclusion requires support with future deep spectroscopy.

These interpretations contradict any proposed lesser age of the Universe and associated values of the Hubble constant H_0 (which expresses the relation between distance and the velocity of expansion, or redshift). A younger Universe was also contradicted in earlier studies showing that the globular clusters of our Galaxy are very old. In both cases, the arguments depend on tracks in the Hertzsprung-Russell (color-vs.-magnitude) diagram for stellar evolution. The distant, very red radio galaxies studied by Windhorst *et al.* thus provide independent evidence bearing on perhaps the most fundmental question in modern cosmology.

The Clustering and Grouping of Galaxies

Of great interest among cosmologists are questions about the large-scale distribution of matter in space. Recent discoveries of various inhomogeneities in the Universe are challenging traditional

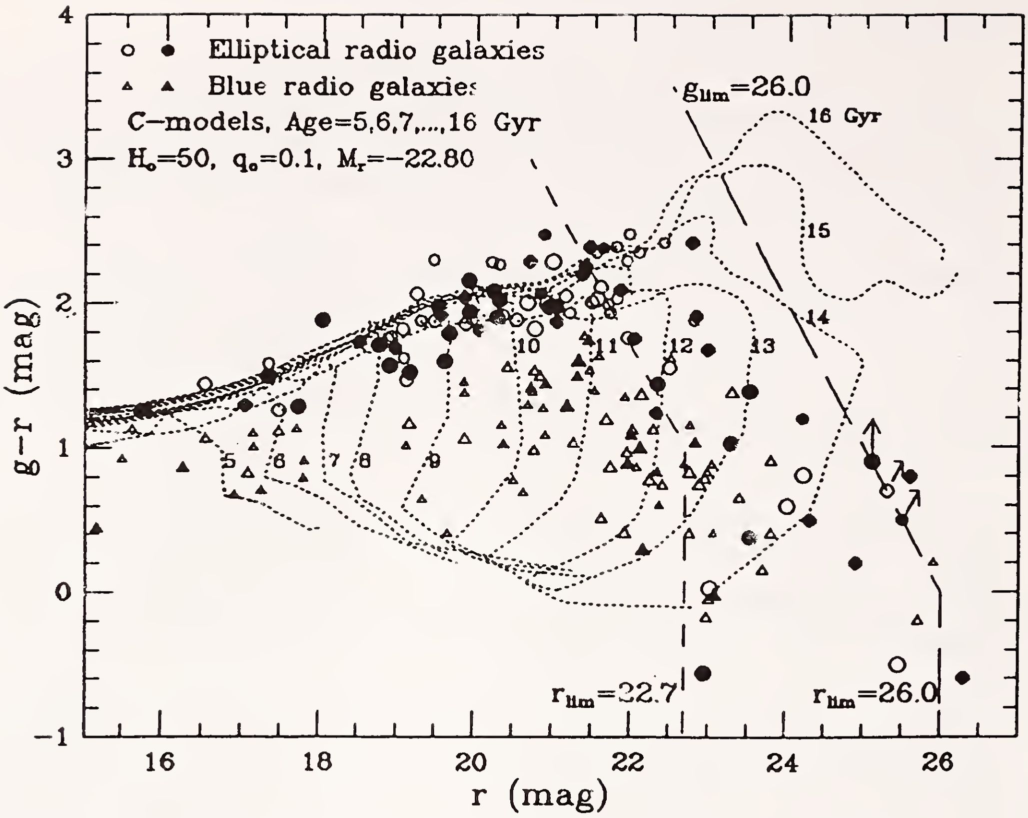


Fig. 9. Color-magnitude diagram for radio galaxies of the sample used by Rogier Windhorst and colleagues for determining the oldest ages of very red radio galaxies. Circles are luminous red ellipticals; triangles are members of the class of blue (merging, interacting) radio galaxies. Notice that there are no galaxies greater in redness ($g - r$) than about 2.4.

The dotted lines represent Bruzual's models of giant elliptical evolution. Note that the model predicts that galaxies of age 15–16 billion years (Gyr) should, in the reddest cases, reach values of redness ($g - r$) higher than the maximum actually observed. A maximum age for elliptical radio galaxies of about 14 billion years is thus suggested.

(Filled symbols are extended sources in the radio, largely coinciding with the giant ellipticals for magnitude r brighter than 22.5. To the left of the dashed line $r_{\rm lim} = 22.7$, the redness scale is in photographic $J - F$, which is comparable to and can be transformed into Gunn $g - r$. Bruzual's passively evolving C-models are computed for a Scalo initial mass function and a wide range of galaxy ages; other parameters are $H_0 = 50$, $q_0 = 0.1$, and $M_r\,(z = 0) = -22.80$.)

views of the formation of the Universe and the nature of its expansion. How evenly or unevenly galaxies are distributed tells much about how galaxies form and evolve. Further, study of close groupings of galaxies offers opportunity to examine the effects of mutual gravitational interactions—in destroying, for example, the relatively nonluminous halos that usually surround spiral galaxies.

In any systematic study of the clumping of galaxies in superclusters, clusters, or lesser groupings, a necessary early step is to pin down definitively whether apparent groupings are real or whether they are merely chance alignments in direction of objects at very different distances from us.

Clusters of Galaxies. Staff member Stephen Shectman of the Observatories has established a sample of 650 galaxy clusters in

previously identified regions of dense galaxy population. The selected sample exhibits a population density in space six times higher than the density of the often-used Abell cluster population, thus promising usefulness for tracing large-scale structure in the distribution of galaxy clusters.

Shectman has begun obtaining radial velocities (and hence, distances) from redshifts of these clusters, in order to determine their distribution in three dimensions. He has accumulated spectra of at least one galaxy in each cluster, and has so far analyzed two-thirds of these spectra to obtain redshifts. By measuring some of these galaxies twice and showing consistent results, Shectman has shown that the quality of the measurements is excellent.

The identification of the members of a cluster is always confused by the possible superposition of alien galaxies or groups of galaxies along the line of sight. To explore this condition, Shectman has obtained radial velocities for two different galaxies in 120 of the clusters of his sample. In 80% of the pairs, the velocities are close enough to indicate that both are members of the same cluster. (The success rate for the Abell cluster sample is not appreciably higher.) The mean difference between the velocities of pair members is a value typical of small clusters of galaxies, a result supporting the validity of the sample.

Shectman has carried out a preliminary analysis of the distribution in space of 309 members of the sample that lie within a given distance range. He finds that the clusters are in many cases grouped in fairly dense knots. (The apparent knots, moreover, are not results of chance superpositions of objects along our line of sight.) There appear to be large volumes where clusters are rare. Below declination 12° in the North Galactic skies, most of the clusters occur at the greater distances studied (21,000–26,000 km/sec in radial velocity).

The correlation function for these 309 clusters, calculated in three dimensions for separations up to 2,000 km/sec, clearly shows that the new sample is clustered ten times more strongly than individual galaxies, a result comparable to that seen in the Abell clusters. At larger scales, however, where the number of independently sampled volumes is small, the correlation function fails to characterize reliably the structure evident in the data.

Galaxies in Compact Groups. In classic work begun in the 1970's, Vera Rubin and Kent Ford of the Department of Terrestrial Magnetism (DTM) showed that a significant component of nonluminous mass appears to be present in outer regions of spiral galaxies. In later investigations of the phenomena in both cluster and noncluster galaxies, the DTM investigators showed that rotational velocity (and mass distribution) patterns of cluster spirals were statistically different from those of noncluster spirals (*Year Book 84*, pp. 55–57). It thus appeared that where galaxies are situated

close to one another, their nonluminous halos are perhaps destroyed in interactions among galaxies or prevented from forming. Investigators at DTM therefore turned attention to a population of galaxies apparently in even more compact groups. The purpose was to investigate the effects of crowded environments on the dynamical properties of the individual members.

It is known that in the rather dense environment of clusters, gravitational interactions among galaxies are rather likely to cause tidal distortions, alterations of galaxy orbits, and galaxy mergers. But in still tighter groupings of galaxies, like those under study by the DTM investigators, the high predicted rate of collision should have long ago caused each grouping to collapse into a single object. How have galaxies in small compact groups managed to survive?

Several answers have been suggested: (1) the compact groups may be merely chance alignments of galaxies at very different distances from us, (2) the groupings, while real, may be only temporary conditions, occurring when the elongated orbits happen to bring the members together, or (3) the tight groupings may have formed recently from looser groups of galaxies, each with an extended nonluminous halo which was stripped in distant encounters, leading to evolution of the compact groups seen today.

Rubin and postdoctoral fellow Deidre Hunter have investigated the groups of four or more galaxies previously identified by Paul Hickson (University of British Columbia)—groups smaller by far, but as densely populated as the rich clusters of galaxies. They have obtained images with a CCD at the 0.9-meter telescope at the Kitt Peak National Observatory. Images were taken through a broad-band *R* filter admitting primarily red starlight and also through a narrow-band filter centered on the Hα emission line of ionized gas, a signal typically emitted in regions of ionized gas associated with active star formation. These images were used to examine the faint outer envelopes of the galaxies in each group for evidence of galaxy interactions—tidal debris, or regions of current star formation. The Hα images were also used to examine elliptical galaxies for the presence of ionized gas—indication that smaller galaxies might have been destroyed in interactions and their gas acquired by ellipticals. (Ellipticals generally do not exhibit ionized gas and active star formation.)

The study to date has been morphological, primarily involving study of the galaxy structures from the images. Conclusions will be stronger when the rotational velocities are measured. Interesting results, however, have been attained, and are seen in the images shown in Fig. 10.

In the shallow exposure of galaxy group H79, the upper left and the rightmost galaxy reveal nonsymmetrical matter in their outer regions—evidence of heavy distortion. In the deep exposure, a peculiar extension is evident to the lower left and right of the grouping, and there is faint outer material enveloping the entire group.

In H57, the galaxies to the upper right show faint outer nonsymmetries (distortions), and in H56 all but one member appears distorted. Thus H79, H57, and H56 are almost surely true groupings.

In most other groups studied, however, distortions are generally milder and less prevalent. H40, for example, is probably not an interacting group, since none of its members exhibit distortions. A few ellipticals in these groups appear to exhibit Hα emission, and they will be examined spectrographically.

In some groups, only a single member shows a peculiarity. In H82, looplike outer structures can be seen in the rightmost galaxy. Galaxy H44d in H44 exhibits interesting structure and arms. H58d is an elliptical galaxy exhibiting a jet extending outward from the center. Rubin and Hunter note that despite the oddities, these groupings are probably only apparent, since distortions are seen in only one member.

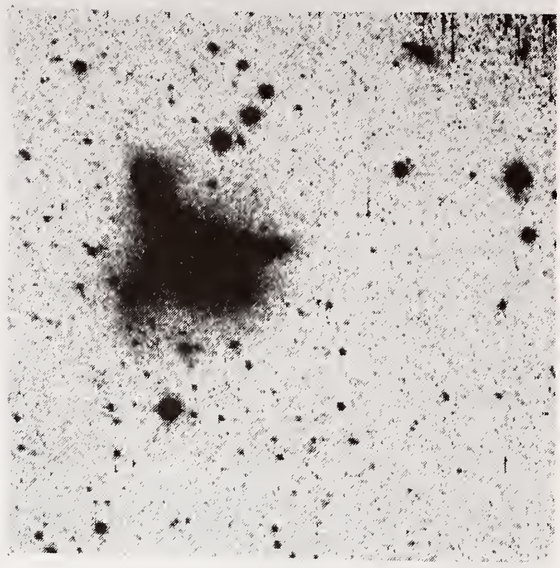
Group H31 is very different from the others, and exhibits many knots of ionized gas in an irregular pattern when seen in Hα. Curiously, there is not much star light outside of these star-forming regions. A long-slit spectrum obtained by Rubin and Hunter at Las Campanas shows that the gas in this system is unusually highly excited. Thus H31 could be a cluster well in the process of merging even though tidal tails—shredded remnants of collisions—are not seen. H31, with its large star-forming knots, resembles a type of irregular galaxy characterized by very large star-forming regions. The investigators note that more data are needed to understand this puzzling system.

Rubin and Hunter's study of the structure of galaxies in compact groups has confirmed that only about 25% of the apparent groups are truly regions of the highest galaxy density. These groups become targets for future rotational studies, which should reveal more of their evolutionary histories and the presence (or absence) of nonluminous matter. Rubin and Hunter note that these compact groups provide an opportunity "to understand the relative importance of heredity and of environment upon the evolution of galaxies."

The Boötes Void Confirmed. A few years ago, Observatories staff members Paul Schechter and Stephen Shectman, working with Augustus Oemler, Jr. (Yale University) and Robert Kirshner (Harvard University) in studying the distribution of galaxies in three small fields about 30° apart, inferred the existence of a vast void largely uninhabited by galaxies, in the direction of the constellation Boötes. Since then, they have conducted a more extensive survey to test the reality of the void. Galaxies were selected from many small fields situated between the three original fields, and redshifts of 239 galaxies have been measured. The results confirm that the void discovered earlier is indeed real, that it is roughly spherical in shape, and that its radius is about 200 ×

H79 R (shallow)

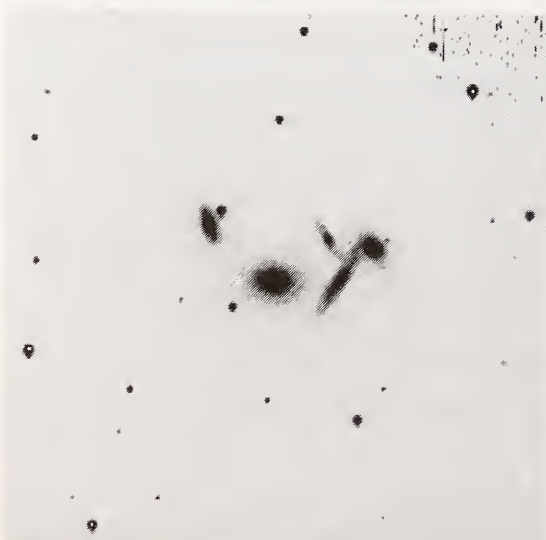
H79 R (deep)



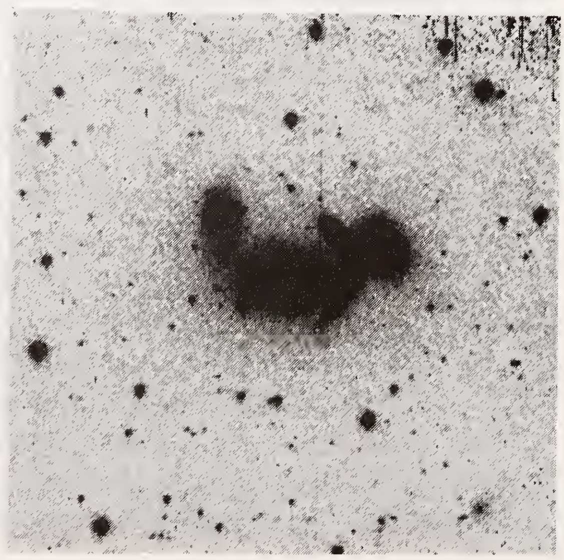
H57 R

H56 R

H40 R (shallow)



H40 R (deep)



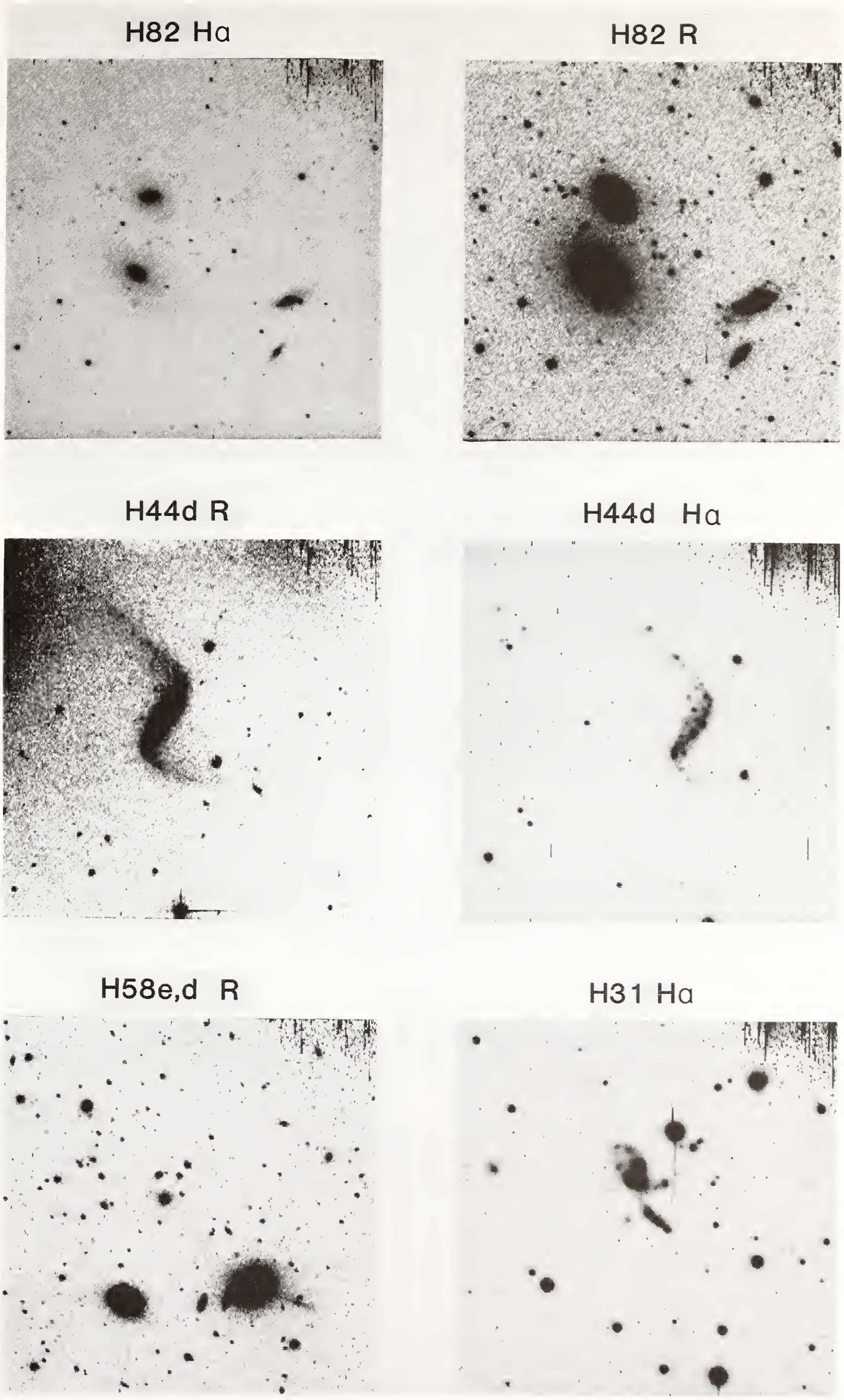


Fig. 10. Twelve images of compact groups of galaxies obtained by DTM's Vera Rubin and Deidre Hunter. See text for explanation.

10^6 light years. The region's low density is of high statistical significance, and does not appear easily reconcilable with any of the familiar models for the growth of structure in the Universe. The void does contain some unusual galaxies having strong, high-excitation emission spectra.

A Large-Scale Motion of Galaxies. The growing evidence of nonuniform large-scale structure in the Universe was paralleled by the recent discovery of a large-scale major streaming motion, one distinct from the general motion attributable to the general expansion of the Universe. The newly discovered motion affects a vast volume of the Universe, 350×10^6 light years in diameter, and is of order greater than 600 km/sec. The motion may have been caused by the gravitational attraction of a distant, yet undiscovered and perhaps nonluminous mass, or it could be the remnant of nonuniform motions induced at or soon after the birth of the Universe. In either case, it seems clear that the expansion of the Universe is less smooth and orderly than was once thought.

The discovery was the work of seven American and British astronomers, three of them with links to the Carnegie Institution—Alan Dressler (staff member at the Observatories), Sandra Faber (a student assistant in 1966 and predoctoral fellow in 1970–1971 at DTM, now at the Lick Observatory and serving also as a Carnegie Institution trustee), and David Burstein (a postdoctoral fellow at DTM 1977–1979, now at Arizona State University). The group has collaborated in obtaining observations of nearly 400 elliptical galaxies; many of the observations were obtained at Las Campanas. Distance was determined for each galaxy using a new method relying on the galaxy's brightness and the orbital speeds of its stars; redshift velocity was routinely measured. Knowing directions and distances, they prepared what was in effect a map displaying the measured velocities, and analyzed the resulting velocity map to reveal the velocity flow.

It had previously been known that our own Galaxy and Local Group had a peculiar velocity of about 600 km/sec with respect to the cosmic background radiation. The investigators now discovered that this same motion was shared by the Hydra-Centaurus Supercluster, and also by galaxies located in the opposite direction, away from Hydra-Centaurus. Thus our own peculiar motion is not caused, as was previously supposed, by gravitational pull of the close-by Virgo Supercluster. It is part of a larger motion characterizing the whole local Universe (see Fig. 11).

The new work is consistent with earlier measurements using different techniques by other researchers, among them DTM's Vera Rubin and Kent Ford. Dressler notes that in the region studied the galaxies are distributed in a greatly flattened configuration, and that the newly discovered flow is in this same great plane. This observation tends to support the model explaining the motion as

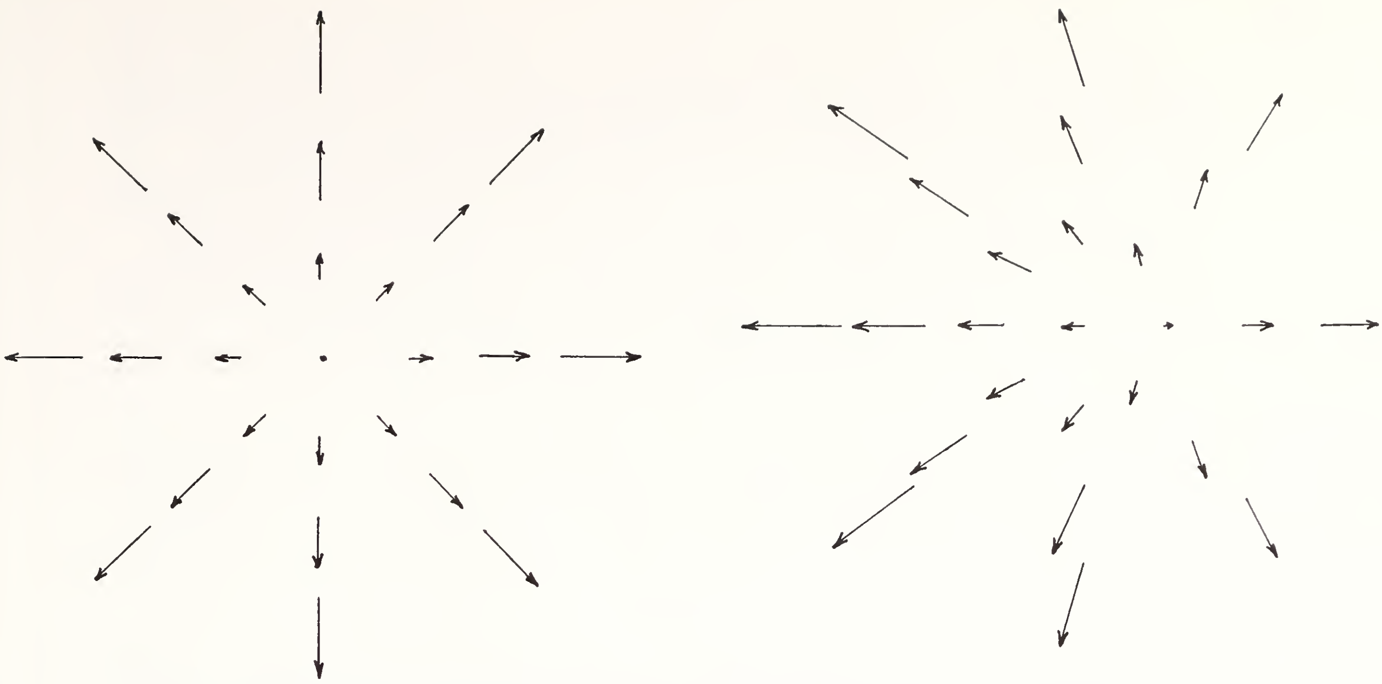


Fig. 11. The sketch at left represents a large region experiencing the unperturbed flow attributable to the expansion of the Universe; to an observer at rest with respect to the cosmic background radiation, all objects appear to be receding at speeds proportional to their distances.

The sketch at right represents the same flow distorted by a uniform flow similar to the streaming pattern recently discovered by Alan Dressler and his collaborators. (Our Galaxy would be represented at the center, and the leftward flow would be in the general direction of the Hydra-Centaurus Supercluster.)

gravitational in origin; perpendicular motion would be expected if the motion were that of an expanding shell (like the remnant of an explosion). The origin of the great mass flow remains uncertain, however, challenging scientific understanding of the distribution of matter in space.

Measuring Mass, Distance, and the Expansion of the Universe

More than fifty years ago, Edwin Hubble and Milton Humason at Mount Wilson demonstrated a linear relation between recessional (redshift) velocity and distance in galaxies, thereby determining that the Universe is expanding. The critical part of this classic work was in determining the distances. For nearby galaxies, the periods of Cepheid variable stars served to tell the absolute luminosities and hence their distances. For galaxies at greater distances, Hubble developed use of the brightest stars in each galaxy as standard candles; at still greater distances, the apparent brightness of entire galaxies allowed a statistical approach satisfactory to confirm that the velocity-distance relation continued to prevail.

The linearity of the relation remains largely accepted today, although Hubble and Humason's distance values have been vastly modified. The slope of the velocity-distance line, as well as the size, age, and mass of the Universe which it dictates, remain yet controversial.

Staff member Allan Sandage at the Observatories has worked for many years to develop various distance scales to pin down definitively the cosmological expansion. The velocity-distance relation is especially difficult to trace in our own part of the Universe because other motions are large compared with the velocity of expansion. Measured velocities have been too inaccurate and precise distance measurements to Cepheid variable stars in nearby galaxies too few to enable definitive answers. Both problems are now largely overcome.

To enable separation of the cosmological velocity component (the velocity attributable to expansion of the Universe) from measured heliocentric velocities, Sandage performed a new solution of solar motion relative to the centroid of the Local Group. He used the assumption that the centroid was on a line connecting our Galaxy with M31—the other large galaxy of the Local Group—and that the motion of the center of our Galaxy was directly toward M31. This solar motion was subtracted from the heliocentric velocities of the nearby galaxies to yield the cosmological components. Corrections were then made for our Galaxy's smaller infall velocity to the Virgo cluster.

The resulting velocities attributable to expansion were then used along with distances obtained from Cepheids, yielding the velocity-distance diagram shown as Fig. 12. The linearity of the result and the relatively small scatter is evident. The slope corresponds to a Hubble constant H_0 = 55 km/sec Mpc, a value indicating that

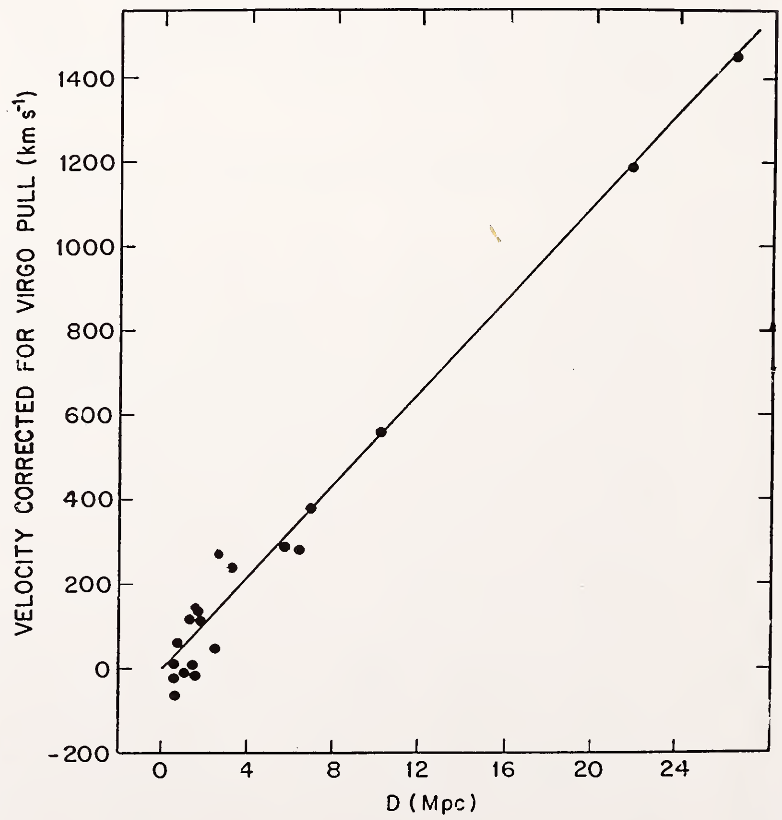


Fig. 12. Allan Sandage's recent plot of recessional velocity, corrected, vs. distance in megaparsecs (1 Mpc = 3.26 × 10^6 light years) from Cepheid measurements, for local galaxies. The two most distant points represent the Virgo and Fornax clusters, whose distances were measured using type I supernovae as standard candles. The linear relation is strong (slope H_0 = 55 km/sec Mpc), indicating that the velocity-distance relation associated with the expansion of the Universe has been shown.

the Universe has been expanding for about 18 billion years. The new result adds support for values of H_0 reached by Sandage in other major studies over the years.

Sandage also computed a family of curves expressing the local deceleration from linearity, assuming that the entire mass of the Local Group is concentrated at the center of mass of our Galaxy and M31. By fitting the curves to the observations, he reached a maximum value for the combined mass of our Galaxy and M31 of 3×10^{12} solar masses. This result fails to indicate the presence of substantial dark matter in the halos of our Galaxy or M31; the idea that large amounts of nonluminous matter are present in the Universe is accordingly discouraged.

Supernovae as Distance Indicators. Sandage and Gustav A. Tammann of the University of Basel, in a venture supported by the U. S. and Swiss National Science Foundations, continued their search for supernovae in other galaxies at the 1-meter Swope telescope at Las Campanas. The objective is to explore and develop the use of supernovae as distance indicators for mapping the size and expansion of the Universe to great distances. Observers from the Astronomical Institute at Basel, working for two years, have obtained over 1,500 plates; eleven type I supernovae have been discovered and nine others have been photographically followed.

An important emphasis has been on finding supernovae in elliptical/S0 galaxies, where internal absorption is largely absent. About 500 elliptical/S0's were surveyed over an effective search time of 1.2 years. According to earlier calculations of supernova occurrence in ellipticals, the effort should have yielded 2.5 type I supernovae. However, no new supernovae were discovered, raising question as to the assumptions underlying the calculations.

The investigators are obtaining and analyzing light curves; if it can be shown that all supernovae have consistent and constant colors, then their value as standard candles will be strengthened. The group is also working to refine the absorption corrections needed for determining magnitudes of supernovae in spiral galaxies, where supernovae are more plentiful.

Working from the 35 known type I supernovae in elliptical and spiral galaxies, Sandage and Tammann reach a global value of $H_0 = 42$, equating to an expanding Universe of 23 billion years.

New Studies of Cepheids. Observatories postdoctoral fellow Wendy Freedman has continued her study of Cepheid variable stars in nearby galaxies; Freedman hopes to refine and extend use of the Cepheid period-luminosity relation as a distance indicator.

An important recent result was her new data for Cepheids in the dwarf irregular galaxy IC 1613, obtained from CCD observations in four colors. This galaxy has long been of much interest, since its Cepheid period-luminosity relation appeared to differ from all

others. Freedman's CCD data indicate that the relation is indeed linear and has a slope consistent with other galaxies, in agreement with photographic data obtained by Sandage.

Meanwhile Freedman, in collaboration with John Graham of DTM and several others, has begun a program to search for Cepheids in several Southern Hemisphere galaxies. A preliminary list of candidate variable stars is being compiled. New data are also being obtained for Cepheids discovered by Graham in NGC 300. Members of the group have also begun a program to determine empirically the effect of chemical composition, or metallicity, on the zero point of the Cepheid period-luminosity relation. Observing at the Canada-France-Hawaii telescope in Hawaii, the investigators obtained measurements of Cepheid fields in M31 and M33 at several radial locations. Since radial gradients in composition are known in these galaxies, the effects of metallicity can be tested.

An Elliptical Galaxy and Its Companions. While it is widely accepted that spiral galaxies are embedded in massive but relatively faint halos, similar arguments concerning ellipticals have rested on x-ray observations of coronal gas, the extent and temperature of which are not well determined. In a quite different approach to the problem, Observatories staff members Alan Dressler and Paul Schechter, with former Carnegie fellow James Rose (now of the University of North Carolina), recently sought to estimate the total mass of an elliptical-dominated system from knowledge of its internal motions. They obtained observations of elliptical galaxy NGC 720 and its several dwarf companions.

Working from a large-scale photograph obtained at the du Pont telescope at Las Campanas, the investigators demonstrated that the grouping of NGC 720 and its companions is real; of 15 galaxies on the plate brighter than visual magnitude 16, six have redshift velocities (and therefore distances) close to that of NGC 720. Moreover, the six exhibit a significant tendency to cluster around NGC 720, which is otherwise quite isolated. Their total luminosity is only 20% that of NGC 720 itself, so it is reasonable to assume that most of the mass in the system resides in NGC 720.

Working from the dispersion in velocity of the six dwarfs about the velocity of NGC 720, the velocity dispersion of stars within NGC 720, and the mean orbital radii from the center of the system of the dwarfs and the NGC 720 stars, the investigators determined a mass 44 times greater than the mass inferred from the luminous stars alone. Although there remains considerable uncertainty, the result appears consistent with the presence of a massive, nonluminous halo.

The Process of Star Formation

Understanding the process of star formation is a central theme in

nearly all branches of astronomy. Our sense of a galaxy's structure and nature is largely a product of our observations of its stars and other luminous matter. The formation of a primordial galaxy from a gaseous cloud must be understood in relation to the accompanying early star formation; the subsequent life-history of a galaxy, then, may be marked by fresh episodes of star formation, perhaps accompanied by gravitational interactions or mergers with other galaxies. The circumstances of star formation are also of interest in reverse—for understanding the extent and nature of matter that fails to form stars, remaining dark. How dark matter around stars may have formed may thus prove fundamental to those who study the interiors of the Earth and other planets.

Observing Young Stellar Objects. Belva Campbell and Eric Persson of the Observatories have continued their investigations of molecular cloud regions harboring Young Stellar Objects (YSO's). These energetic objects, believed to be stars in the process of formation, are embedded in opaque envelopes and are characterized by bipolar outflows of molecular gas (*Year Book 84*, pp. 70–73). In hopes of discovering previously undetected YSO's, Campbell and Persson, working at the 2.5-meter Las Campanas telescope, searched sky regions previously identified by the IRAS orbiting infrared telescope. Eliminating those sources having inappropriate energy distributions in the near-infrared or other disqualifying features, Campbell and Persson were left with a population of at least 15 new YSO's, each characterized by opaque envelopes and bipolar outflows. Deep CCD pictures of all the fields were obtained for morphological studies; infrared spectroscopy is planned.

Meanwhile, in observations with the Four-Shooter CCD camera at the Palomar 5-meter telescope, Campbell and Persson further studied the classic YSO, GL 490. In their model, a circumstellar disk of material, optically thick, surrounds the YSO; the face of the disk on the near side is tilted toward us, the geometry allowing some light to reach us without passing through the full thickness of the disk plane. Campbell and Persson have turned their attention to the positional offset previously noted between the optical and radio centers of the GL 490 central source. Believing that the observed optical features are explained by the scattering of light, they predicted that the separation between the optical/near-infrared centroid and the radio centroid should vary with optical/near-infrared wavelength: the largest offset should occur for the bluest image.

Campbell and Persson have found similar offsets in two other YSO's. NGC 7538 IRS 1 is an extremely luminous, high-mass YSO, 9,000 light years distant; its unresolved optical image is removed from the radio centroid in the direction of its blueshifted outflow. YSO Lynds 1551 IRS 5 is only 450 light years away, so that a more detailed view of its optical features is possible. The recent

observations show that the separation between the optical/near-infrared and the radio centroids changes with the optical/near-infrared wavelength, as predicted by Campbell and Persson. The position angle of the shift is very close to the direction of the blueshifted side of the outflow and that of the jet-like structure seen in the plots. The observations serve as a kind of probe of the circumstellar disk, and Campbell and Persson are working to develop a simple model for the disk consistent with the data.

In another investigation, Campbell combined Four-Shooter CCD frames of fields containing YSO's GL 490 and GL 961 with deep maps of the same regions made at the Very Large Array radio telescope and with flux maps from the IRAS infrared satellite. Her purpose was to investigate the possible presence of YSO's more deeply embedded and less luminous than those already known in these regions. Preliminary results indicate that such a population may indeed exist. Campbell's view of the radio source associated with GL 490 was at ten times higher sensitivity than that of any previous radio observation; the observations suggested the presence of previously unsuspected emission in the circumstellar disk, over and above that of the ionized mass-loss flow from the YSO itself.

Last year, Persson and Peter McGregor reported that the spectrum of the active galaxy I Zw 1 bore strong resemblance to the spectra of YSO's. Similar features in I Zw 1 and YSO spectra appeared to be associated with material heavily shielded from ionizing photons from a central source. In the galaxy, the source may be the inner regions of an accretion disk around a black hole; in the YSO, it is the newly formed star and its immediate environment. Persson and McGregor have continued to explore the phenomenon, working with spectra from other Seyfert galaxies and YSO's, and they note one case where the geometries of the YSO and Seyfert galaxy are highly similar apart from the size-scaling factor of several thousand. George Preston writes that if subsequent work continues to support the view that a single model explains star-forming activity in both realms, it will be a remarkable generalization.

Observations of Herbig-Haro Objects. Astronomer John Graham, a staff member at DTM and an adjunct staff member at the Observatories, has begun a study of star formation in dense molecular clouds. He is observing Herbig-Haro objects (HH objects)—faint, nebulous regions often seen near the dark cloud cores which are believed to harbor stars in early stages of formation. Exploiting the fine photographic imaging possible over a moderate-sized field at the du Pont 2.5-meter telescope, Graham has succeeded in resolving certain nearby HH objects into a multitude of almost star-like knots. Graham is also performing CCD imaging over

smaller fields at increased sensitivity, thereby finding additional features of very low surface brightness.

Graham hopes to study how a young star interacts with the surrounding dust and gas left over from its birth. Some of this material may collect into primitive planetary bodies. Evidence is growing that such dust may be heated and in turn sorted by frequent flaring of the new star and simultaneous generation of a strong stellar wind. An outburst observed recently by Graham and Jay Frogel (National Optical Astronomy Observatories) near HH 57 is an example of such an event. This year, observing at Las Campanas, Graham noticed that the reflected surface brightness of HH 46 has apparently increased by a factor of 5–10 during the last two years.* The source of the illumination itself (embedded in the larger dust cloud) is not directly visible, but the increase in the scattered light around it suggests that the embedded star is flaring or that the enveloping dust shell is slowly clearing.

The work may provide an important observational link between the star-forming and planet-forming processes.

The Existence of Dark Stars. The stars we see by naked eye all derive their energy primarily from the fusion of hydrogen into helium. As long as a sphere of hydrogen gas contains at least 8% the mass of our Sun, it will be hot enough to undergo fusion.

But what about gaseous systems of lesser mass? The process of cloud collapse and fragmentation could very well produce objects having mass less than 8% the Sun's. Such objects, though essentially nonluminous, are clearly stars not planets. (By definition, stars form directly through the collapse of interstellar clouds; planets are formed by secondary processes occurring around stars.)

Theoretical models of cloud collapse, designed to yield detailed mathematical descriptions, are based on the equations of gas hydrodynamics. To produce a realistic model of protostar formation, a number of physical effects must be included: stars are held together by self-gravity, and are supported against collapse by thermal pressure. In addition, since young stars rotate much faster than older stars like our Sun, angular momentum must be important during the formation process. Reinforcing this point is the frequent occurrence of double-star systems, where the angular momentum stored in the orbital motions far exceeds that stored in the spin rotation of each star. Thus, self-gravity, thermal pressure, and rotation are all surely required in star-formation models. In the modeling the cloud must be permitted to distort in all three spatial dimensions, to accommodate the possible formation of many stars. And because the process is also time-dependent, the solution must be four-dimensional in space and time.

---

*An announcement appeared in IAU Circ. 4213.

DTM's Alan Boss has spent ten years developing theoretical models which include these phenomena. Development of the necessary numerical techniques for solving the governing equations required much ingenuity. It was necessary, for example, to implement a method for following the flow of radiation in all three spatial dimensions—a crucially important aspect for determining the thermal pressure in early phases of star formation. (If the cloud is sufficiently dense, the radiation is trapped in the cloud and its energy contributes to the thermal pressure of the gas.) Calculation of the models has required large amounts of computer time, made available by continuous use of the Institution's VAX computers on low-priority basis. In 1985, the Institution installed an array processor, which will further speed the modeling effort.

One important result of Boss's work is an estimate of the minimum protostellar mass. Since stars are much less massive than interstellar clouds, collapsing clouds must fragment into smaller objects to form stars. It has long been hypothesized that a hierarchy of fragmentation takes place, where a cloud fragments into pieces which themselves collapse and undergo further fragmentation. The smallest protostar is then determined by the smallest fragment at the cessation of fragmentation. Fragmentation may be expected to stop when the fragments become sufficiently dense to trap their radiation and thereafter increase their gas temperature. The numerical methods developed by Boss allow this process to be rigorously modeled.

The models imply that, while hierarchical fragmentation is unlikely to involve the many stages formerly hypothesized, at least a few stages are plausible. By examining the outcomes of runs spanning all possible initial conditions for interstellar clouds and their fragments, Boss showed that a lower bound on the minimum mass of a protostar is about 1% the Sun's mass. This minimum mass is about ten times the mass of Jupiter, the largest known planet.

If stars this small exist, Boss writes, then some tantalyzing possibilities appear. It would mean that a new population of stars, between 1% and 8% of the Sun's mass, exists in our Galaxy, waiting to be discovered. Any "brown dwarfs" that are members of binary systems can be sought indirectly through astrometric methods, by detecting and measuring wobble in certain visible stars. Although brown dwarfs have not been observed beyond doubt, wobble measured in several nearby stars is usually attributed to an unseen binary companion. In these cases, the astrometric solutions and unsuccessful infrared searches for the unseen companions restrict any brown-dwarf companion to a mass between 1% and 5% the Sun's, roughly consistent with the theoretical minimum mass.

Because hydrogen fusion does not occur, brown dwarfs can only radiate the energy produced by compression during the collapse phase. They are thus luminous for only a short period after their

formation, making direct detection difficult. The Space Infrared Telescope Facility planned by NASA will perhaps enable observation of newly formed brown dwarfs.

It is possible that once hierarchical fragmentation is started, it may be hard to stop. If so, there may be many brown dwarfs, and their combined mass could make up a large fraction of the total mass of the Universe. Brown dwarfs are prime candidates for constituting the missing mass identified in studies of galaxies.

Understanding Our Galaxy and Its Neighbors

The remarkable gains in instrumentation and technique that have advanced the deep observation of faint, distant objects, have also brought new opportunities for observing detailed features of our own Galaxy and its neighbors at high resolution. These relatively close-by subjects are of intrinsic interest, as parts of our local Universe; they also offer a singular means of addressing more-general questions about the processes of galaxy formation and evolution.

The Formation of Our Galaxy. Correlations between the orbital properties of stars and their chemical compositions offer evidence on physical processes during formation of our Galaxy. A conventional picture holds that the spheroidally distributed stars formed early in the collapse of what became the Galaxy and are therefore poor in elements heavier than helium; in contrast, stars of the rotating disk were formed later in the collapse of gas and dust enriched in the heavier elements.

Astronomers recently recognized the Galaxy's thick disk—a component somewhat outside the more densely populated thin disk along the Galactic plane, and whose stars appear intermediate in property between those of the thin disk and the halo. The thick disk offers a population of stars whose characteristics might explain the physics of bulge-star and disk-star formation. Seeking to distinguish a population of thick-disk stars from overlapping distributions, Observatories visiting investigators Gerard Gilmore (Institute of Astronomy, Cambridge, England) and Rosemary Wyse (University of California, Berkeley) have been measuring chemical abundances and kinematics of F and G stars in a volume where the thick disk is assuredly the dominant component. Preliminary results from measurements of about 1,000 such stars confirm that many have kinematic and chemical properties intermediate between those of the extreme spheroid and the thin disk. Gilmore believes that these stars provide a natural solution to the "G-dwarf problem," where there is an absence of old stars near the Sun having heavy-element abundances approximately one-tenth the Sun's. These are the stars that are most common in the thick disk.

The mothballing of the 2.5-meter Hooker telescope at Mount

Wilson in 1985 coincided with completion of Allan Sandage's long-term program of observations to map the Galaxy's halo. Photometric and radial velocity data from the venture have been published, and Sandage and Gary Fouts, now of Computer Sciences Corporation, have completed their analysis of the data. A foremost result is that the distribution in heavy-element abundance [Fe/H] of the halo is distinctly different from that of the thick disk. A distinct change in the formation history of these components appears to be indicated. Sandage envisions, however, that the process of collapse was largely continuous, where the differences between the halo, the thick disk, and the thin disk components were produced by two appreciable changes in the slope of the collapse-rate vs. heavy-element-enrichment–rate relation. The data, he concludes, support a continuous and coherent process of Galaxy formation, where discontinuities result from differences in cooling rates during the collapse.

An Intensive Look at the Center of Spiral Galaxy M33. Two decades ago, Vera Rubin and Kent Ford conducted a long-term study of M31—our Galaxy's magnificent sister. Their measurements of the dynamics of M31 became an early step in their systematic investigation of rotation and mass distribution in spiral galaxies. Their detectors and spectrographs were advanced for the day but were far less capable than today's equipment. Even so, given M31's proximity to us, Rubin and Ford were also able to look closely at regions of the nuclear bulge and develop valuable conclusions.

Rubin and Ford now report recent high-resolution spectroscopic observations of the central part of the spiral galaxy M33. A neighbor of M31 but much smaller, M33 also possesses a beautiful spiral structure outlined by well-defined emission regions. The nuclear bulge is relatively small, and a nearly pointlike object, or semistellar nucleus, can be detected close to the very center.

Rubin and Ford used the Palomar 5-meter telescope with double spectrograph and CCD detector to observe the spectral characteristics of the central region. Figure 13 is an image of the innermost region of M33, photographed with Hα filter. The major axis of a 2′ spectrograph slit is shown, with the semistellar nucleus centered thereon.

The resulting spectra were unusual in that the semistellar nucleus exhibited Hα in absorption rather than in emission. (The powerful Hα emission from excited hydrogen in the disks of spirals creates the strong line customarily used in studying galaxy rotation.) If M33 were more distant, then the width of the slit would necessarily include not only the nucleus but also a larger contribution from the disk; the absorption at the nucleus would be swamped by contamination from disk emissions. More generally, Rubin and Ford note, measured ratios of intensities [NII]/Hα in galaxies are characteristically influenced by the distances of galaxies from us. (In galaxies

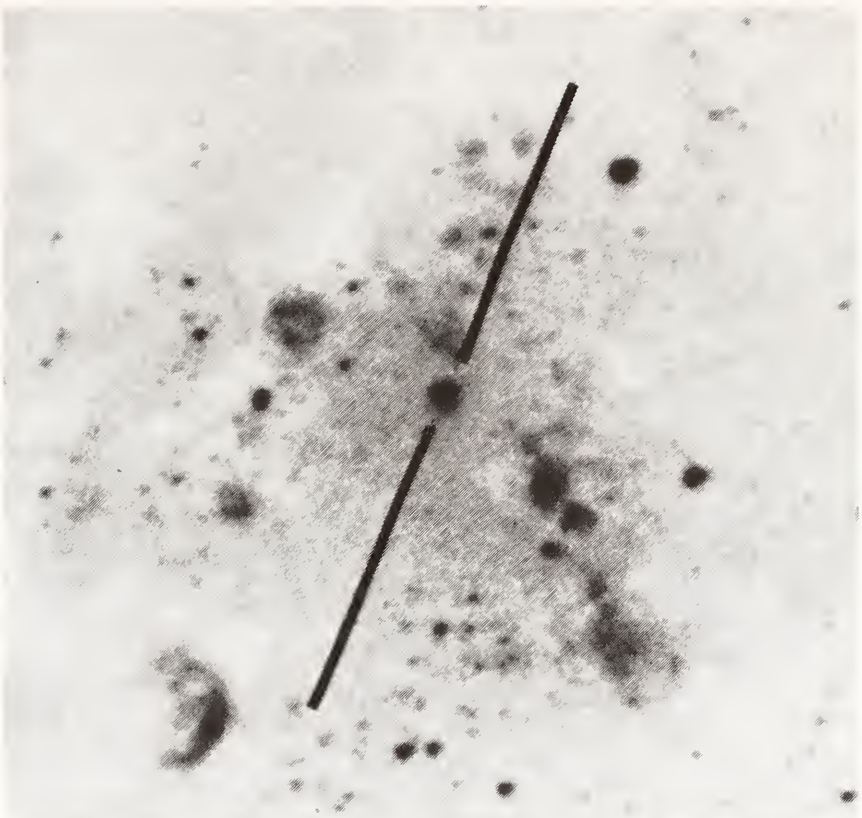


Fig. 13. The inner region of spiral galaxy M33, imaged with Hα filter. The semistellar nucleus, which lies close to the exact dynamical center, is shown at the center of the 2′ spectrographic slit, which is aligned with the major axis of the galaxy. (This plate of M33 was taken by Malcolm Smith, then a staff member at the Cerro Tololo Inter-American Observatory, with the Cerro Tololo 4-meter telescope.)

at large distances, Hα absorption at the center is overwhelmed by disk emission, so measured ratios tend to be artificially low.)

From their observations of M33, Rubin and Ford conclude that the nucleus, which apparently contains a negligible amount of neutral hydrogen, is therefore chemically distinct from the disk. Plotting observed wavelengths in the inner region either side of center, Rubin and Ford found unmistakable evidence of rotation (see Fig. 14). A steep gradient is evident across the center, leveling into a surprisingly flat curve over the inner region. Radio observations of the neutral hydrogen show that rotational velocities rise beyond this flat portion. This curious pattern has important implications for the distribution of mass near the center of M33, a matter now under study.

There is a small but distinct displacement of the center of symmetry when determined by the optical velocities. This displacement, while real, would be unobservable in more-distant galaxies. Ford and Rubin explain this small-scale asymmetry (as well as larger ones noted earlier by other investigators) by noting that M33 contains a remarkably small nucleus and bulge: it simply lacks a dominant gravitational entity to define the exact dynamic center.

Both in M31 and in M33, Rubin and Ford found a complex

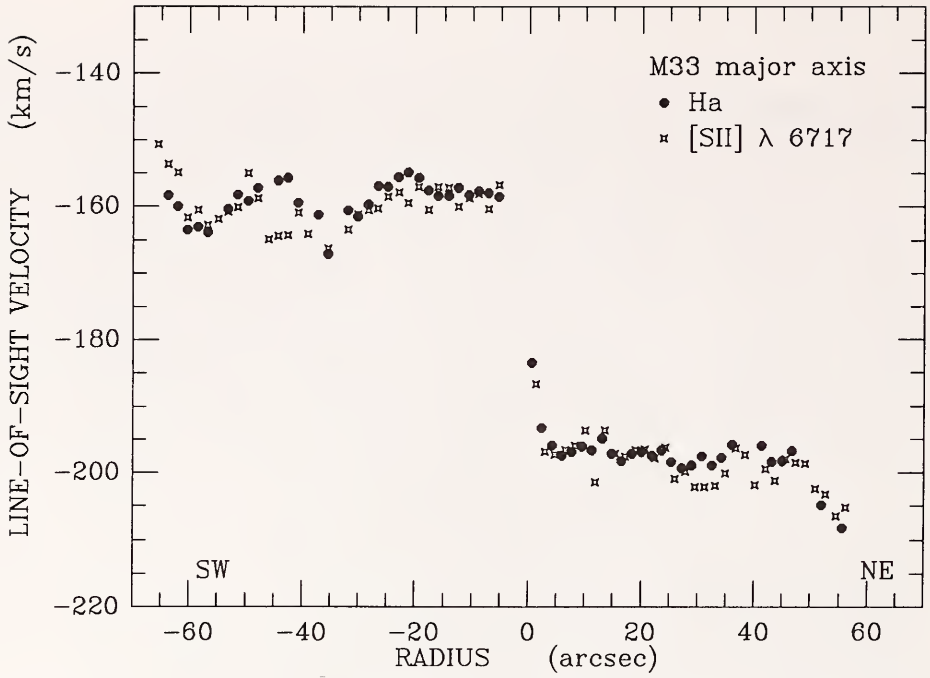


Fig. 14. Rubin and Ford's rotational curve showing change in apparent velocity across the center of the inner regions of M33. The wavelength (velocity) shift either side of center is marked; the dynamical center is offset slightly (about 2 arc seconds) from the position of the semistellar nucleus, a feature reflecting the lack of a strong gravitational entity at the center. Measurements in Hα and the emission line of S[II], both shown here, yield similar results. Radio observations in HI by other investigators reveal that the velocity of rotation increases beyond this flat inner region.

pattern of velocities in the inner region, though in both cases rotation is clear-cut. They note that higher-resolution observations, obtainable soon with the Hubble Space Telescope, should increase knowledge of the nuclear properties of M33 and other nearby galaxies.

Interstellar Dust in M31. Several years ago, Observatories staff member Leonard Searle showed that the properties of the interstellar dust in M31 change in a systematic way along the radius of its disk (*Year Book 82*, pp. 622–624). As his probe, Searle used M31's globular clusters, some of which lay in front of the absorbing dust sheet, others behind. Searle found that the wavelength dependence of this absorption changed across the galaxy's disk.

Searle and Ian Thompson now report further investigations of this phenomenon using the new detectors now available at Palomar; they have expanded the sample of globulars and the wavelengths studied, and have used infrared photometry obtained by collaborators Eric Persson, Bel Campbell, and Keith Matthews (Caltech).

The new study strengthens the earlier conclusions. Extinction in the violet (for a given reddening in $V - K$) is large when the obscuring dust is near the center of M31 and small when it is at the periphery of the disk. The change is roughly linear out to radii where values are close to those found in our own neighborhood of our Galaxy.

The dust responsible for interstellar reddening is thought to have been formed in, and then ejected from, the atmospheres of cool evolved giant stars. There are two common types of such stars, Carbon stars and M stars, whose atmospheres contain free carbon and free oxygen, respectively. In our Galaxy, the ratio of these two types of stars is known to vary systematically with distance from the center of the Galaxy. It seems likely that the radial variation in the dust properties of M31 has its origin in a similar change in the populations of dust-producing stars.

Preston believes that the final idea is an intriguing one. "It would be remarkable and exciting if the relationship is in fact a causal one," he writes.

Star Formation Rates as a Clue to Galaxy Evolution. Were the galaxies of the early Universe similar in their Hubble type (i.e., according to their observable features) to the galaxies seen today? Or has there been substantial evolution of galaxy form accompanying the continuing star-formation process, such that the original galaxy configurations are no longer recognizable?

There are several ways to address such questions. One is to look at very distant galaxies in order to observe the Universe as it was at a much earlier time. Another is to measure present star-formation rates in galaxies; rates can then be compared with the supply of hydrogen gas available for further star formation in galaxies, thereby predicting when star formation will nearly cease. Results can be translated into estimates for past star formation, giving indication of past galaxy evolution.

Allan Sandage has taken the second approach, combining past star-formation data with new calculations of present gas consumption in galaxies of different types. His calculations for certain galaxies of the Local Group and the nearby Virgo cluster indicate that the hydrogen yet remaining in these galaxies will be consumed in less than the present age of the Universe, thereby indicating that there is rapid change in the galaxy population even today. The conclusion is subject to assumptions, seemingly reasonable ones, as to the lower limit of stars formed in each star-formation episode.

Sandage has also concluded that the properties of galaxies can be understood by the behavior of a single variable—the time rate of change of the star-formation rate ($dSFR/dT$). In galaxies with bulges (ellipticals, S0's, and the centers of Sa's and Sb's), $dSFR/dT$ was very large at early times, such that most stars were formed in a short time compared with the collapse time of the gas. Gas dissipation was small, and no disks (or small disks only) resulted (see Fig. 15). In disk-dominated systems (Sc's, Sd's, and Sm's), the opposite is true.

Sandage points out that this picture appears capable of explaining changes in bulge-to-disk ratio, disk surface brightness, integrated color, mean disk age, and present star-formation rate per unit

mass, which for Sc galaxies is much larger than for E, S0, and Sa galaxies but was much smaller in the past. The detailed physics of the *dSFR/dT* function remain for the future, Sandage notes.

The Eight-Meter Telescope Project

The 8-meter telescope idea has stimulated much mental energy at the Observatories. What should be the scientific expectations for the facility? To what extent should there be provision for research methods having no current interest but of possible future importance? Such questions were translated into technical issues as to space allowances in the telescope enclosure and the placement of foci.

Progress in practical matters was evident. The search for a Project Manager was completed upon the appointment of W. Albert Hiltner. A site-testing program was initiated at various locations on the Las Campanas grounds, using equipment constructed under the supervision of Eric Persson. An inquiry was begun as to needed alterations for the mountain road to allow safe transport of

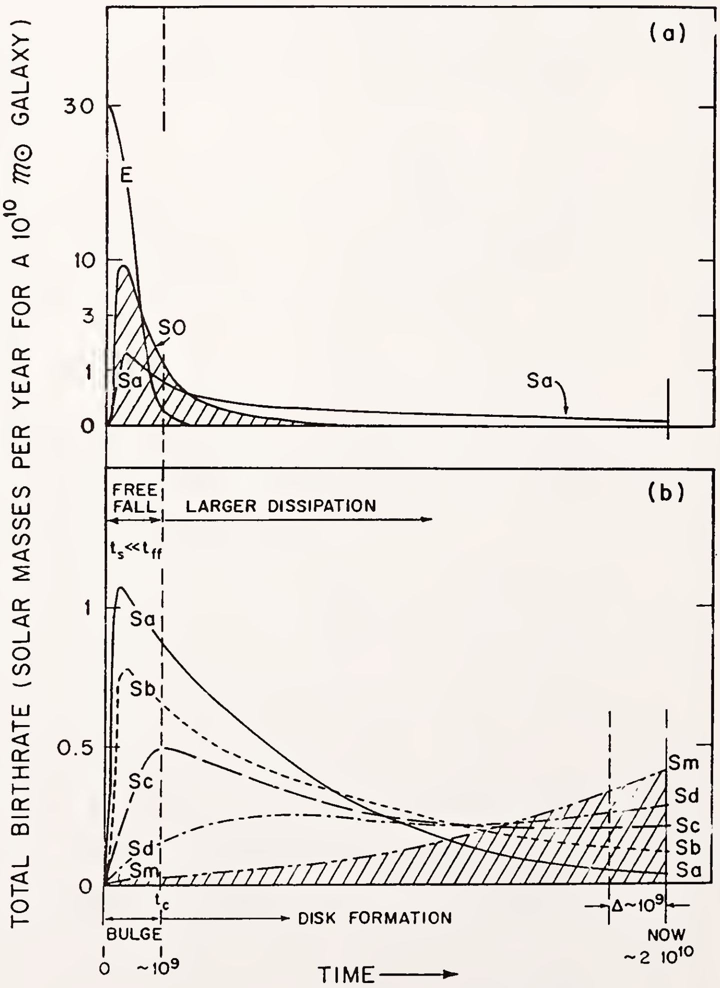


Fig. 15. Variation of the rate of star formation with time (*dSFR/dT*), from recent calculations by Allan Sandage of the Observatories. Bulge-dominated galaxies (ellipticals and S0's) perform most of their star formation in their early evolution. The vertical dashed line represents time for the initial gas to collapse, and it separates bulge from disk formation. (The areas under the S0 and Sm curves are hatched for clarity.) Measurement of *dSFR/dT* thus offers an indication of a galaxy's evolutionary situation.

the mirror from the port city of Coquimbo to Las Campanas.

Such matters required close interaction with scientists at the University of Arizona and the Johns Hopkins University. Preston writes that the conduct of these dialogues with colleagues elsewhere was itself a learning experience for himself and the staff. Although his enthusiasm for the future telescope is unlimited, Preston notes that "while we may wish or vow otherwise, the telescope project is bound increasingly to divert the attention of Carnegie astronomers from their more traditional academic efforts as involvement deepens."

Solar and Stellar Observations at Mount Wilson

Although the 2.5-meter Hooker telescope was mothballed in June 1985, as planned, the Carnegie Institution entered informal agreements for the use of other facilities at Mount Wilson by visiting investigators, and continued to provide certain financial support for observatory operation and maintenance. The Institution continued working to encourage outside investigators and their institutions to organize a consortium or plan for the future scientific and financial operation of the facility.

Observations with the solar tower telescopes continued under memoranda of understanding between Carnegie and UCLA (for the 150-foot telescope) and the University of Southern California (for the 60-foot telescope). Several of Carnegie's skilled mountain personnel were hired by these universities. The continuous, long-term observations of solar velocity and magnetism, obtained at the 150-foot tower telescope since early in this century, were thus extended under the supervision of UCLA's Roger K. Ulrich. The historical continuity and accuracy of the Mount Wilson data are invaluable for studying the dynamics of the Sun's interior through new analysis methods, such as those of helioseismology. Analysis of intensive solar oscillation data—obtained recently at the 60-foot tower every 40 seconds for up to 11.5 hours per day in certain periods—yielded estimates of the rotation of a large part of the Sun's interior.

The 60-inch telescope remained dedicated to nightly observations of stellar magnetic and activity cycles, under partial support of the National Science Foundation. More than 165,000 independent observations of some 2,000 main-sequence and giant stars are contained in the computer-based archive, covering the years 1966–1986.

It seems likely that the history of astronomy on Mount Wilson, as well as the role of the solar and solar-stellar physicists as a link between astronomy and the earth and planetary sciences, is far from over.

The Accumulation of the Planets

> It is clear to those of us working on the formation of the solar system that... only a few engaged in this quest are likely to be present when the goal is reached. This need not lead to despair. There are many specific problems of the kind discussed here that must be addressed before a well-ordered understanding of planetary formation can be realized. Knowledge that there are these well-defined steps to be completed can give substance to our individual efforts, and offset the tendency to climb our personal Mount Pisgah and proclaim too strongly our individual vision of the distant Promised Land.
>
> George W. Wetherill
> July 1986

Attempts to understand the formation of the solar system are proceeding from two directions. One approach, taken by Alan Boss and others, starts with observational evidence of star formation in giant molecular clouds and uses physical theory to work forward in time. The other approach is to start with the present system of planets and go backward, one step at a time, to identify plausible prior conditions. A satisfactory understanding of the entire problem requires that the two approaches meet at some point, though at present a gap remains that can be bridged only qualitatively.

This year, DTM director George Wetherill and Glen Stewart of the University of Virginia, using the second approach, have worked backward from the late stage of planetary accumulation where bodies roughly of lunar size merged to form the terrestrial planets—the stage studied by Wetherill in past years. The recent objective of Wetherill and Stewart was to evaluate how these lunar-sized bodies may themselves have evolved.

The venture required a theoretical technique very different from that used by Wetherill earlier. The number of accumulating bodies is so enormous that it would be impossible to follow the evolution of the individual bodies by techniques of orbital dynamics. Instead, Wetherill and Stewart treated the system in a more collective way, making use of techniques adopted from the kinetic theory of gases.

Using this approach, Stewart developed new expressions for the velocity evolution of a swarm of small planetesimals. The theoretical basis for his expressions is much stronger than those used by others studying the problem. Wetherill then used these expressions as the basis for a numerical method for calculating the velocity and mass evolution of a growing swarm of small bodies.

In his numerical simulations of this early stage of growth, Wetherill encountered a bifurcation. One possible path of growth

agrees well with that found by earlier investigators—Safronov and Hayashi, whose work was the starting point for Wetherill's past studies of late-stage accumulation. The other possible path is that of a runaway growth, where within each of a number of small concentric zones, growth is dominated by a single body, which swallows up all the smaller bodies capable of making a close encounter with it.

The later stages of this runaway are not amenable to either of the two theoretical approaches now available, and the final outcome of the runaway cannot be quantitatively determined. However, plausible qualitative arguments can be presented indicating that the final stage of accumulation will involve even larger bodies than had been employed in Wetherill's earlier work. The number of these large bodies is considerably greater than the known number of final terrestrial planets. Therefore the collection of these bodies into planets will still be dominated by giant impacts, as Wetherill suggested earlier.

Mineralogy at High Pressure

A new chapter unfolded this year in the development at the Geophysical Laboratory of methods and equipment for studying materials at high pressure. Investigator J. S. Xu (from the People's Republic of China) and staff members Ho-kwang Mao and Peter Bell obtained sustained pressures of 5.5 megabars in a diamond-anvil cell apparatus. They succeeded in measuring this pressure using the ruby fluorescence effect, previously thought to be unusable above 2 megabars.

The new diamond-anvil designs were based in part on a laser-probe, finite-element stress analysis of the anvils. Actual stress-distribution measurements in three dimensions were begun during computer-controlled experiments with a new microfocus laser diode-array spectrograph. (The latter is designed to measure simultaneously the Raman effect and the thermal black body radiation of samples at high pressure and temperature.)

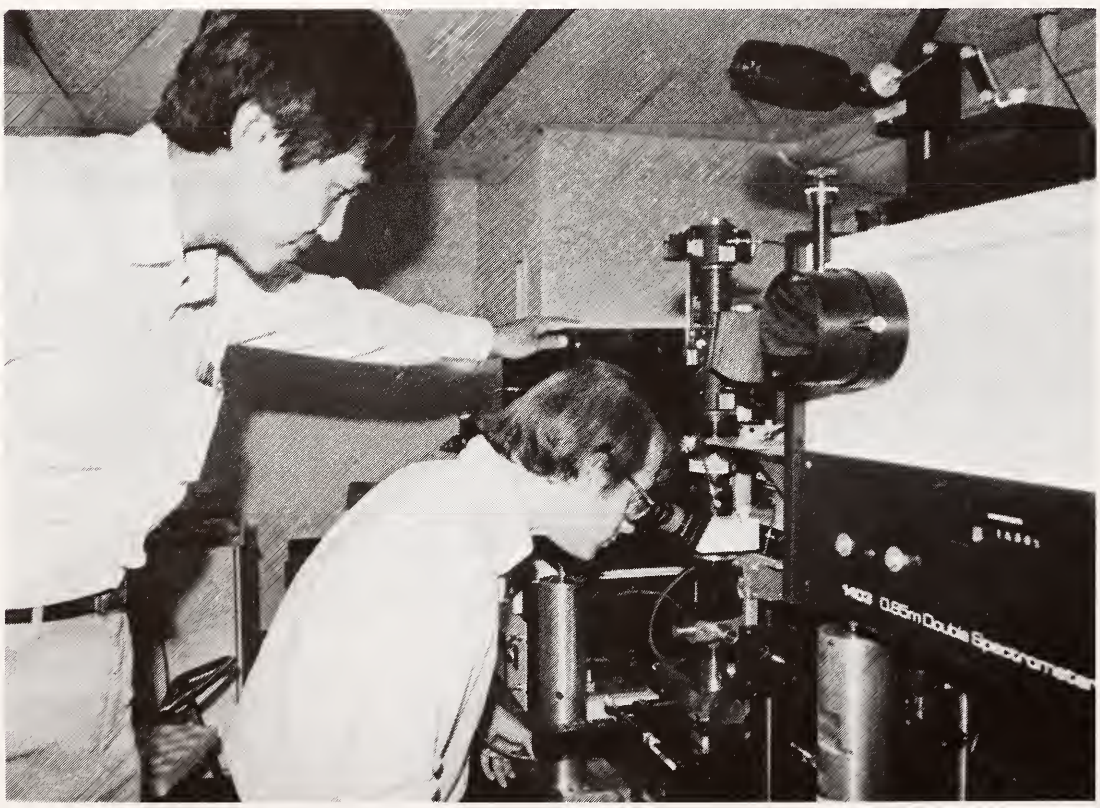
The new capability with the diamond cell means that experiments are now possible at static pressures equal to those at the Earth's center (3.5 megabars). Experiments can also be done at upper-mantle conditions of the major planets—above about 3 megabars in the case of Jupiter, for example. (The pressure at Jupiter's center is perhaps 100 megabars.)

The next development in high-pressure technology is likely to involve the application of controlled high temperatures inside the diamond-anvil cell. To duplicate the most extreme conditions in the Earth, temperatures on the order of 7000K will be required at 3.5 megabars. It may be possible to generate these conditions by internal resistance and laser-beam heating, but because of the

intense heat the conditions probably cannot be held stably for longer than several minutes. The Geophysical Laboratory investigators are now developing faster observing techniques so that heating damage to the diamond anvils and other components of the apparatus can be avoided.

Experimental Results. Seeking to determine the phase of iron that would be stable under conditions of the Earth's core, Bell and Mao have been studying the compressibility of iron. They have recently investigated the ϵ-γ phase transition curve, a fundamental observation critical in predicting the melting point and all other properties of the outer and inner cores. They observed the transition in a diamond cell apparatus, heated by internal resistance to a maximum temperature of 1673K at maximum pressure of 360 kilobars—the highest pressures and temperatures at which the transition has been observed in static high-pressure experiments. The new results suggest that the iron of the inner core may have the ϵ (hcp, hexagonal closest packed) crystal structure. However, postdoctoral fellow Andrew Jephcoat, with Peter Olson of Johns Hopkins University, has shown that the density of the inner core is significantly less than estimates based on pure hcp iron.

In high-pressure experiments at room temperature, Mao, Xu,



Ho-kwang Mao and Russell Hemley use the recently installed optical spectrometer at the Geophysical Laboratory for making Raman measurements on minute amounts of material contained in a high-pressure diamond-anvil cell.

and Bell measured the compressibilities and densities of two garnets—andradite and grossularite. Their purpose was to evaluate seismically derived models of the mantle's transition zone (depth 670 km). In order to obtain the most reliable interpretation of data at 150 kilobars—the pressure existing at the "garnetite zone" at the center of the transition zone—the investigators obtained data to 300 kilobars. They found that the presence of andradite tends to decrease the compressibility and increase the density. As the grossularite component is increased, the compressibility is unchanged but the density is decreased. Their results made it possible to determine the effects of calcium, aluminum, and ferric iron on the physical properties of garnets at the pressures studied.

Several programs of experiment at the Laboratory explored the vibrational properties of materials under infrared or x-ray excitation at high pressure. Studies of forsterite, fayalite, and γ-Fe_2SiO_4 by Anne Hofmeister, Mao, Bell, and Thomas Hoering have shown that thermodynamic properties at high pressure (e.g., heat capacity and Gruneisen parameter) can be accurately calculated from the vibration spectra. The results were used to derive phase diagrams, which proved consistent with results of phase equilibria experiments. An olivine-spinel geotherm for the mantle agreeing with seismic derivations has been reached from these studies. Postdoctoral fellow Russell Hemley, with Hofmeister and others, obtained the first definitive vibrational spectra (Raman and infrared) of stishovite, the highest pressure phase known of SiO_2. Results resolved past controversies as to the lattice dynamics, structure, and heat capacity of this important mantle mineral. These and other ventures offer critical data needed to formulate general theoretical models of the inner Earth, to be tested by data from seismic and geochemical observations as well as in further experiments.

Using Synchrotron Radiation with the Diamond Cell. In recent years, synchrotrons have become important sources of radiation in the x-ray wavelengths. These machines, which produce radiation through the deflection of high-energy electrons in a magnetic field, have low beam divergence, a uniform wavelength spectrum, and a high intensity. In contrast, conventional laboratory sources of x-rays produce a divergent beam where most of the relatively low intensity is concentrated at a few discrete wavelengths. Because synchrotron sources are rare, access to them is usually obtained through peer-reviewed proposals, like those required by government granting agencies. As members of the Powder Diffraction Participating Research Team at the National Synchrotron Light Source, Brookhaven National Laboratory—the group that constructed this beam line—Geophysical Laboratory scientists have priority access to the Brookhaven facility.

Since the early days of x-ray scattering experiments, the technique has been to subject a high-quality single crystal to a primary x-ray

beam. The radiation scattered by the sample, which may also comprise a powder of small crystallites in random orientation, is recorded by a counter system. Crystal structure is then deduced. When using synchrotron-generated radiation, the low beam divergence results in instrumental resolution as much as ten times that of a conventional x-ray spectrometer. Closely spaced details can be resolved with much less ambiguity. Further, synchrotron radiation makes it possible to solve the unknown structures of geological systems where it is difficult to grow relatively large single crystals, needed for the older method.

In one mode of operation, the uniform wavelength distribution of the synchrotron enables a complete beam spectrum to be focused upon a sample. A solid-state detector analyzes a small angular range of the scattered beam. Thus, the entire spectrum can be collected at one time, the experiment time is reduced, and only a small volume of sample is required. This mode is especially useful for experiments with the diamond cell, where the region of uniform pressure is quite small.

Looking ahead to future synchrotron experiments at high temperature and at those very high pressures where only a small sample can be accommodated in the diamond cell, several Geophysical Laboratory investigators recently conducted trials at Brookhaven. Samples of silicon, gold, iron, and ruby were studied to obtain compressibility data and establish calibration scales. Pressures were calibrated by lattice-parameter measurements and by x-ray–induced ruby fluorescence. The trials reached a maximum pressure of 1.4 megabars, and the investigators concluded that the promise of synchrotron radiation for diamond cell experiments was indeed great.

Plate Subduction: Seismological Studies

The Earth's continuing evolution is seen in the production of new crust and lithosphere at the midocean ridges. The new material, formed into rigid plates, moves away from the ridges at speeds of several centimeters per year. Where plates collide, the motion of one turns downward, and its material returns to the interior by the process known as subduction. Seismologists and geochemists at DTM seek better understanding of subduction processes, in part because subduction regions produce most of the world's volcanos and larger earthquakes. But subduction regions and processes are also of scientific importance for the remarkable evidence they offer as to the nature and activity of the deeper Earth.

As an oceanic plate plunges beneath an older, lighter plate at a subduction zone, large seismic events occur at relatively shallow depths (70 km or less), sometimes producing devastating earthquakes. Two kinds of mechanisms cause most such events: (1) the initial bending at the trench causes tensional faulting in the relatively

stiff, subducting plate, or (2) interaction between the descending plate and the adjacent lithosphere causes thrust, or compressional, faulting.

Less well understood are the mechanisms of deeper earthquakes, which have been seen to persist to depths as great as 670 km. These events, however, are helpful in illuminating the nature of the descending plates, or slabs. The locations of slab-related earthquakes can indicate a slab's geometry, and the associated seismic radiation patterns tell of the modes of stress release and allow estimates of stress distribution within the slab. Seismic signals from unrelated earthquakes can also reveal the presence of a very deep slab: a slab is much cooler (by 500–1000°) than the surrounding mantle, and therefore exhibits higher seismic velocities and lesser attenuation, i.e., a detectable seismic signature.

Major questions abound. Why is there a gap in the distribution of earthquakes beneath South America between 300 and 500 kilometers of depth? Do slabs descend deeper into the mantle than the 670-km cutoff? Are descending slabs part of a *mantle-wide* circulation of heat and material (convection), or is the mantle above 670 km essentially isolated from below?

Slab Penetration beneath Peru. The unusual geometry of subduction beneath Peru provides an ideal opportunity to study the descending slab and the forces affecting it. Since 1965, investigators from DTM and the Universidad de San Agustín at Arequipa have deployed seismographs in the region and have acquired observations from thousands of events, most of them occurring at depths between 50 and 300 km. From these data, Selwyn Sacks of DTM and Akira Hasegawa (Tohoku University, Japan) several years ago mapped the slab beneath Peru (see *Year Book 84*, p. 87). Beneath central Peru at depth of about 100 km, the subducting slab ceases its standard 30-degree angle of descent and proceeds horizontally. Then after about 300 km of horizontal travel, the slab again turns downward. But beneath southern Peru, this unusual horizontal path is not seen. Between the two regions, Sacks and Hasegawa showed, the slab is contorted but continuous; the zone of contortion is about 80 km wide.

Seeking to explain this behavior, Sacks noted that the more northern region (central Peru), which has had no recent volcanic activity, exhibits very low heat flow, so that the temperature of the South American plate overlying the slab is relatively low. The slab is potentially buoyant if it is sufficiently young and cool enough to retard the phase transformation to a denser configuration. In typical subduction, at sufficient temperature and pressure the basaltic crust of the slab transforms to a denser form, eclogite, which probably represents the most dense phase in the upper mantle. As a result, the slab becomes denser than its surroundings. Sacks proposed that beneath central Peru, the slab is buoyant

because the basalt-eclogite phase change is retarded by the low temperature at the base of the overlying continent. Normal subduction resumes where the basalt-eclogite change finally occurs farther east.

Research associate John Schneider and Sacks are studying focal mechanisms of these same intermediate-depth earthquakes as a means of investigating the forces associated with the contorted region; the pattern of stress release gives a measure of the stress field within the slab. The special geometry of the region makes it possible to distinguish between alternative models for forces acting on a subducted slab.

One popular model explains the seismicity and stresses by the bending of the subducted slab. Where the bend is concave upwards, compressive forces occur near the upper surface; tensional forces will occur for the opposite flexure. Beneath central Peru, between the early 30-degree dip and the horizontal section at 100-km depth, there is a substantial concave-upward bend. Farther east, the resubducting slab has opposite curvature, i.e. concave downwards. But in both regions the focal mechanisms were found to indicate plate tension; i.e., the new data indicate that bending is not a dominant seismogenic factor.

Thermal expansion in the slab has also been proposed as a possible source of stress. (Investigators in Japan have explored this hypothesis in extensive models to explain the unusual seismicity beneath Japan.) Temperature patterns beneath Peru allow a test of the concept. In central Peru, the horizontal slab remains relatively cool, as its upper surface is isolated from the hot, mobile asthenosphere. To the south, in the "normal" subduction region, the slab contacts this hot material below about 70 km. If thermal effects were dominant, the seismicity should be higher in the southern region. But if anything, the reverse is the case. Thus thermal expansion seems to have no role in the region.

Sacks and Schneider conclude that the dominant mechanism for producing stresses in the slab is the gravitational "tugging" of the slab itself. This conclusion is supported primarily by analysis of the transverse forces and the focal mechanisms, both in the contorted region and to the north. The crucial finding is that the forces outside the contorted region correspond not to the local geometry but to the force associated with long-term sinking in the south. All forces point toward the gravity potential well beneath southern Peru (see Fig. 16). Thus the sustained pull from gravity is the overriding factor; the seismicity is not attributable to the high strain caused by bending and contortion, which by lowering viscosity decreases the earthquake potential.

The absence of earthquake activity below 300 km in Peru does not mean that the slab fails to penetrate beneath this depth. Downward tension is still seen at 300 km, so that there must be gravitational pull from below (and slab material below to provide

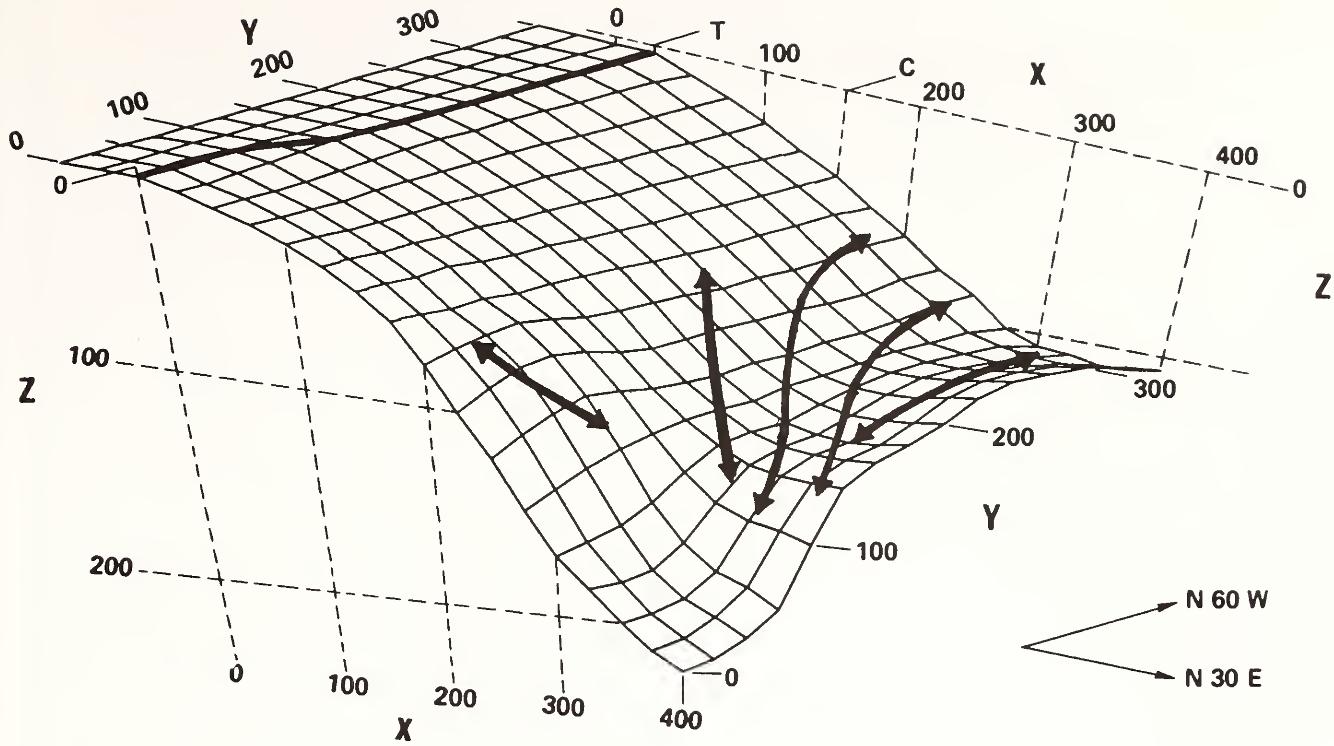


Fig. 16. Subduction of the Nazca Plate beneath southern Peru. The arrows designate tension within the plate indicated by microseismicity. Force patterns within the zone of contortion beginning at about 80-km depth indicate that the dominant mechanism for subduction is the downward pull of the descending plate at lower depth.

this pull). But because there is less slab beneath this depth to pull downward, there is less stress to produce seismic activity. Then, near the discontinuity at 670 km (which exists worldwide), the viscosity surrounding the slab increases, and the slab no longer sinks freely but is resisted. This reversal in stress direction produces a minimum-stress regime between 300 and 500 km, and explains the absence in seismicity between these depths.

Sacks notes that if these results can be extended to other subduction zones, they may explain the global minimum in seismicity at similar intermediate depths.

Studying Slabs at Great Depths. The study of slab penetration (or its absence) below 670 km entails the analysis of seismic waves whose travel is affected by the slab itself at depth. DTM's Paul Silver and Winston Chan have studied several unusual body waves produced by earthquakes just above 670 km in the northwestern Pacific and recorded by stations in North America. Silver and Chan detected multipathing—a phenomenon where a seismic signal takes various, slightly different paths from its place of origin to a given station. (The variations in wave travel result from some heterogeneity along the pathway.) The investigators determined that the feature accounting for the observed multipathing is localized in the lower mantle just beneath the earthquakes, and that the feature exhibits high seismic velocity. Silver and Chan believe that

they are probably seeing evidence that the slab extends downward into the lower mantle to about 1,100 km.

Silver and Chan are expanding the multipathing work to the study of slab penetration beneath South America; they hope to investigate the lower mantle beneath 670 km as well as the seismically inactive region between 300 and 500 km beneath Peru.

The Great Chilean and Sumbawan Earthquakes. Interested in very large earthquakes and ways to predict them, and hopeful of insights into basic forces and motions within the Earth, Paul Silver has been applying unusual tools to the study of rupture characteristics of several major earthquakes.

Silver and DTM predoctoral fellow Ines Cifuentes recently examined seismic data from the Great Chilean Earthquake of 1960—the largest earthquake ever recorded (magnitude 9.5). The event ruptured nearly a 1,000-km length of Chilean coastline. Some ten years ago, investigators elsewhere (from study of strain seismogram signals recorded at Caltech) proposed that the Chilean earthquake was preceded by a slow event, comparable in magnitude to the main event but of much longer duration. Now, using a recently developed technique, Cifuentes and Silver have examined free-oscillation data of the Earth in order to estimate the low-frequency (long-period) characteristics of the slow earthquake. The Earth's free oscillations are analogous to vibrations generated by striking a bell; their periods are the longest (up to one hour) of any earthquake radiation. The proposed slow earthquake precursor should have had a significant effect on the free oscillations.

Silver and Cifuentes intensively analyzed more than 300 free-oscillation amplitudes, with periods in the range of from 200 to 1,000 seconds, obtained at eight stations (most of them installed during the 1957 International Geophysical Year). The amplitudes in the 1–3 mHz band (300–1,000 seconds) were found to be consistent with the generally accepted picture of a 1,000-km-long rupture, slip of about 20 meters, and rupture velocity of 3 km/sec.

The DTM investigators have found that the data in the 3–5 mHz band is not explained by the usual earthquake model and are now investigating the presence of another event. This event may be the proposed precursor and, if so, would indicate that the Great Chilean Earthquake of 1960 is not like other earthquakes.

The Chilean earthquake resulted from severe relative motions between a subducted and a buoyant plate. In contrast, the Sumbawan earthquake of 1977 (magnitude 7.9), just seaward of the Java trench, resulted from tensional faulting within the descending slab. Scientists have disagreed whether the event represented a rupture from the bending of the slab just before its subduction or whether it represented a cracking of the entire slab—torn apart by the pull of the slab at greater depth. A determination of the extent of faulting should give the answer: if faulting occurred throughout the

full 80-km thickness of the slab, then the entire slab must have broken apart. But if faulting occurred only to about 40 km, then mere bending would have been responsible.

Collaborating with several colleagues at M.I.T., Silver examined the free-oscillation data between periods of 100 and 1,000 seconds. They found that the data could only be fit by models where faulting was primarily confined to the top half of the slab.

Silver noted that only the use of the free-oscillation data, in particular the simultaneous consideration of the relatively broad band of 100–1,000 seconds, made possible the result. More-conventional seismic data is of course of interest; but because the event was so large, the body waves saturated nearly all the instruments of global networks. Silver noted, however, that the DTM broadband system, which has high dynamic range, obtained several unique on-scale recordings, which may provide keys for understanding the process of plate bending near the beginning of subduction.

Sediment Subduction in Volcanic Arcs: Answers from ^{10}Be

Ever since seismologists demonstrated that volcanic arcs like the Aleutians and the Andes are associated with zones of subduction, a major question has been whether oceanic sediments, as well as the oceanic crust on which they lie, are involved in subduction and associated magma formation. Are the sediments carried downward with the descending plate to depths of magma formation, where a fraction of the sediment enters the magma sources, eventually to reappear as surface lavas? Research over twenty years has led many scientists to believe that sediments probably are subducted beneath volcanic arcs, but there has been no certain evidence on the point; most geochemical tracers are subject to equivocal interpretation.

One exception is the isotope ^{10}Be, which originates in the atmosphere through cosmic-ray bombardment of oxygen and nitrogen and is carried by rainfall to the oceans, where it subsequently builds up in bottom sediments. Its short half-life (1.5×10^6 years) means that only very recent processes and very young sediments can impart a ^{10}Be signature to volcanic arc materials, thus avoiding some of the ambiguity associated with other geochemical tracers. And because the source is atmospheric, mantle-derived rocks such as midocean ridge and oceanic island basalts contain essentially no ^{10}Be ($<0.5 \times 10^6$ atoms/gram, vs. the $5{,}000 \times 10^6$ atoms/gram typical of oceanic sediments). Thus, the incorporation of even a small amount of young, oceanic sedimentary matter into a magma source should produce measurable ^{10}Be concentrations.

From measurements of nearly 200 samples at the University of Pennsylvania's tandem Van de Graaff accelerator, DTM investigators

and their colleagues at the University have concluded that volcanic arc lavas are, in fact, the only volcanic rock type that contains ^{10}Be. ^{10}Be concentrations in arc lavas range from 0.1 to 24 $\times$ 10^6 atoms/gram. Some arcs, such as the Aleutians and Chile, exhibit a very narrow range in values. Others, most notably Central America, Japan, and the Kurile-Kamchatka arc, show wide ranges. The ^{10}Be data, when coupled with geological, geophysical, geochemical, and sedimentological information for each of the arcs and associated subduction trenches, provides an excellent basis for studying the sediment incorporation process. DTM investigators Julie Morris, Fouad Tera, and Louis Brown are making important progress in this work, and they are developing a quantitative model explaining ^{10}Be content in lavas.

An uncertainty has been whether sediments are actually subducted to depth beneath volcanic arcs or whether arc lavas include sedimentary material acquired by assimilation when rising as magma through near-surface sediment layers. Measurements from southern Chile allowed Morris and Tera to rule out assimilation during ascent, since all near-surface sediments in Chile are too old to contain ^{10}Be. Their result is the strongest possible evidence indicating that sediment is subducted downward into the Earth's mantle at zones of subduction.

The appearance of ^{10}Be in lavas requires that there be enough ^{10}Be in the sediments to produce the observed concentration after only a small percentage of the sediment is mixed into the magma source material. Because of its short half-life, the ^{10}Be content of a sediment is dominated by the last 8–10 million years of sedimentation. It is therefore reasonable to look for correlations between ^{10}Be in a lava and measures of recent sedimentation. (Heavy recent sedimentation offshore should be accompanied by high ^{10}Be readings in the associated lavas.) Initial data seem to indicate that this is indeed the case (Fig. 17), except that samples from Mexico consistently contain little ^{10}Be despite high recent sedimentation. (Geological evidence shows that much of the sediment fed into the trench in Mexico is being scraped off and not subducted, perhaps explaining the low ^{10}Be concentrations.)

The DTM investigators are trying to evaluate quantitatively other factors explaining why sediments appear to be subducted in some arcs but not in others. Of special interest are the physical parameters governing plate subduction and the fate of the associated sediments. One suggestion is that young slabs, which are hot, buoyant, and thus resistant to subduction, are less likely to carry down sediment than are older slabs. This may be true in Mexico, where the arc is being underthrust by a young, 10-million-year slab. But in Chile, where the age of the slab varies from 40 million years in the north to 10 million years in the south, ^{10}Be is measured in similar concentrations all along the arc.

Other physical processes may affect ^{10}Be distribution. Both in

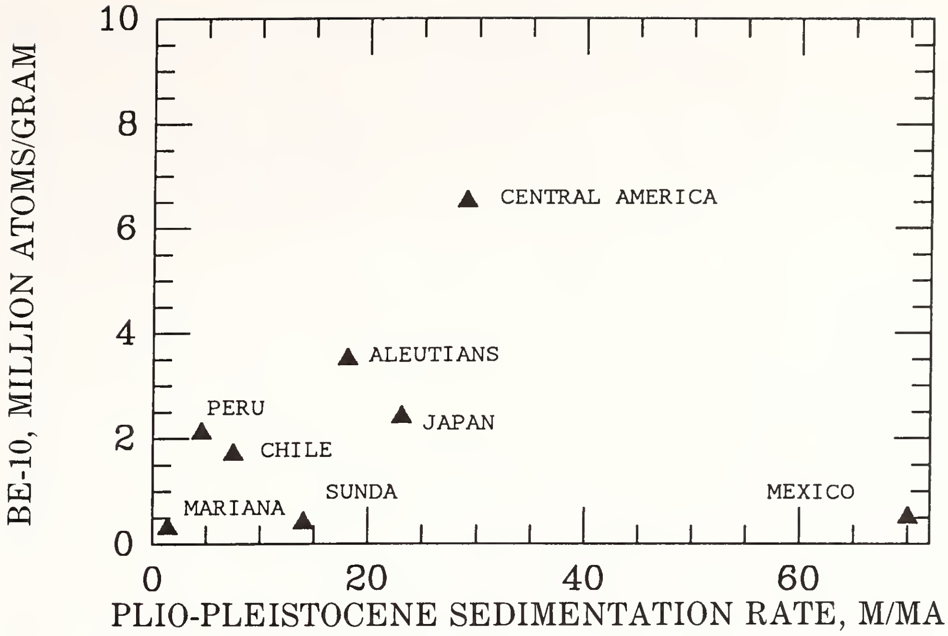


Fig. 17. In general, where recent sedimentation is heavy, associated arc lavas exhibit high ^{10}Be content. Shown here, average ^{10}Be concentrations vs. recent (Plio-Pleistocene) sedimentation rates, measured outboard of the offshore trenches. Sediments in Mexico are scraped away from the subducting plate, perhaps explaining the anomalous readings in that region.

Japan and Chile, there are localized sites of very high ^{10}Be concentration. These sites lie above topographic irregularities in the subducting slab which have produced down-dropped sediment-filled basins. These basins may provide the means for enhanced sediment subduction, a result that is important for models of subduction zones.

A major question in arc petrology is the fate of the subducted slab. Does it melt a little? Does it melt a lot? Is it simply devolatilized? Unlike most other elements, ^{10}Be is uniquely associated with the slab and hence may ultimately yield some insight into what happens to the slab at depth. In a previous comparison of ^{10}Be data with those of an Sr, Nd, and Pb isotope study of Chilean lavas, Morris showed that ^{10}Be is decoupled from these other isotopes, suggesting that the ^{10}Be transfer mechanism from the slab may be complicated. Seeking to learn constraints on the transfer process, Tera and Geophysical Laboratory staff member Bjørn Mysen are preparing a series of Be-partitioning studies between diopside and water-rich fluid at mantle temperatures and pressures.

Another important factor in determining ^{10}Be concentrations in arc lavas is the time required for transport of the sediments from the offshore trench where subduction begins, to the zone of magma generation at depth. The subduction time varies from about 2 million years in Central America and the Kuriles to about 11 million years in the Lesser Antilles. This variation, which corresponds to six half-lives, must be accommodated in any analysis of ^{10}Be concentrations in lavas.

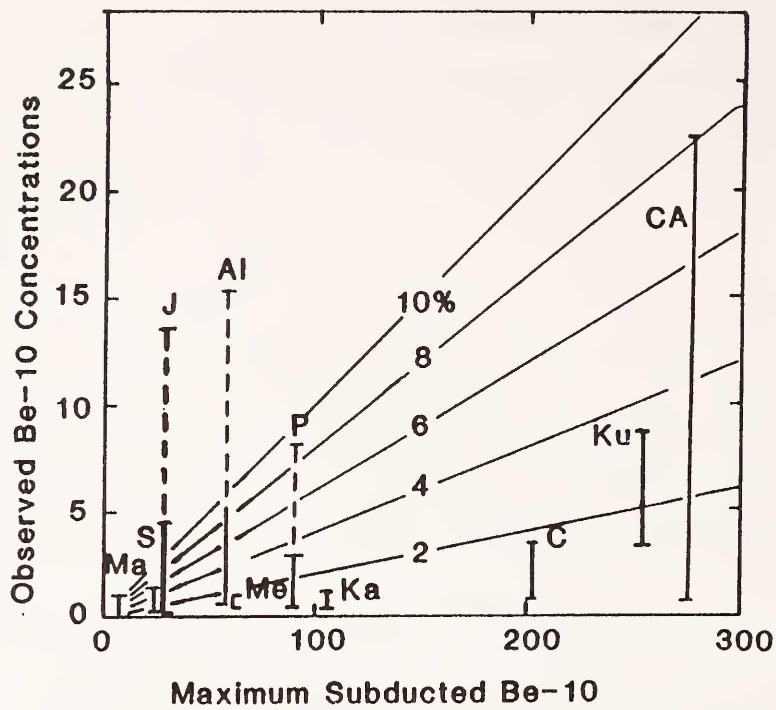


Fig. 18. The DTM investigators are developing a model predicting ^{10}Be concentrations in volcanic arc lavas. Shown here are theoretical maximum values of ^{10}Be concentration (horizontal scale) in various lavas, calculated primarily from offshore sedimentation rates and decay during the subduction process. Measured values for various arcs appear as vertical lines: CA, Central America; Ku, Kuriles; C, Chile; Ka, Kamchatka; P, Peru; Me, Mexico; Al, Aleutians; J, Japan; S, Sunda; Ma, Marianas. (Dashed segments show where a single reading lies anomalously outside the range of all others.) The diagonal lines represent amounts of sediment incorporated in the lavas, expressed as percentages. Note that the model successfully predicts a lack of ^{10}Be in the Mariana and Sunda arcs, and explains the difference in ^{10}Be content in the Kurile and Kamchatka segments of the Russian arc. In the Marianas, for example, if as much as 10% of the lava material were from sediments, the measured concentration of ^{10}Be would not be appreciably altered.

Application of the quantitative modeling by the DTM investigators is illustrated in Fig. 18. The model uses the relationship between ^{10}Be concentration and sedimentation rate (as in Fig. 17) along with ^{10}Be decay during subduction, to predict the maximum possible ^{10}Be contents of various arc lavas. Several factors that may be important in detail are ignored, but the model does a remarkably good job of predicting which arcs should show low ^{10}Be concentrations and which should have high concentrations.

Morris *et al.* conclude that although ^{10}Be may be useful for studying the mechanical processes of sediment subduction, such processes are generally of secondary importance in accounting for ^{10}Be concentrations of arc lavas. But despite uncertainties in the detailed interpretation, the results provide clear evidence that arc lavas include a small percentage of sedimentary material, introduced through subduction. It is theoretically possible that an atom-

by-atom accountability through the different parts of the production-sedimentation-subduction-eruption cycle can some day be made. Thus, ^{10}Be may ultimately be useful for detailed study of that cycle, as well as of other processes in ocean sedimentation and bottom transport.

Geochemical Investigations of the Inner Earth

The Mantle beneath the Oceans. Chemical and isotopic data from volcanic rocks erupted at the surface reveal details of their mantle source regions. For example, basalts erupted in ocean basins within the past 180 million years have varied Sr, Nd, and Pb isotopic compositions—evidence of long-lasting >1–2 billion-year-old) heterogeneities in the mantle. Geochemists are applying detailed examinations of the chemistry of these heterogeneities to such problems as the nature and depth of mantle convection, the identity of specific reservoirs in the mantle, how heterogeneities are distributed in the mantle, and how they are related to larger earth processes.

Sea floor samples are recovered by dredging from regions of volcanic island chains. Shown here, dredge assembly on the fantail of the RV Thomas G. Thompson, at sea in the Mariana Volcanic Arc. Dredge is lowered overboard and dragged along sea floor. (Photo by DTM geochemist Julie Morris.)

DTM staff member Steven Shirey, in collaboration with investigators at the University of North Carolina, Charlotte, and at the Lamont-Doherty Geological Observatory, has recently studied a region south of the Azores, near the intersection of the mid-Atlantic ridge and the Oceanographer transform fault. The tholeiites analyzed were generated by spreading at the midocean ridge, and most represent the products of mantle upwelling at a single spot over the last million years. Using closely spaced samples collected by other investigators directly on the ocean floor with the Alvin submersible, and combining trace-element data with various isotope measurements, the group has been able to identify the distribution of heterogeneities on the small scale.

From measurements of trace elements and Sr, Nd, and Pb isotopes, Shirey and colleagues have divided the samples into three distinct groups. Groups A and B are similarly enriched over Group C in the incompatible trace elements. There is, however, remarkably large dissimilarity in $^{143}Nd/^{144}Nd$ and $^{206}Pb/^{204}Pb$ among all the groups. In general, the isotope data require that components have originated from three portions of the mantle that had been chemically distinct for hundreds of millions of years.

The Groups B and C samples can be interpreted within a previously proposed pattern of mantle heterogeneity in the region—one involving variable degrees of mixing betweeen normal midocean ridge basalt and enriched mantle having Azores-like isotopic composition. However, Group A remains isotopically unique, having lower $^{143}Nd/^{144}Nd$ and $^{206}Pb/^{204}Pb$ relative to values of the Groups B and C samples. This feature, along with relatively low $^{207}Pb/^{204}Pb$ and high $^{208}Pb/^{204}Pb$, rule out the involvement (as source for Group A) of mantle enriched by the recycling of continental or pelagic sediments, or enriched mantle characteristic of most other ocean-island sources.

Combining the isotope data with key trace-element ratios (e.g., Ce/Sm, Ce/Zr, and Ba/Y), Shirey and colleagues find that the Group A material exhibits characteristics of the enriched subcontinental mantle previously identified by DTM geochemists under the ancient Wyoming and southern African (Kaapvaal) cratons. The shape of the region on the ocean floor containing the Group A samples suggests that the mantle source may be an isolated "plum," which is being actively melted during upwelling at the midocean ridge (see Fig. 19). Since this region is not related to a strong ocean-floor bathymetric high or to an active ocean-island "hot spot," it must be a passive feature fundamentally different from an active plume.

Shirey believes that this enriched mantle feature may have been removed from the colder subcontinental lithosphere by hotter mantle flow related either to subduction at a continental margin or to an upwelling plume. Either mechanism provides a way for the deeper parts of the cratons, heretofore considered a permanent

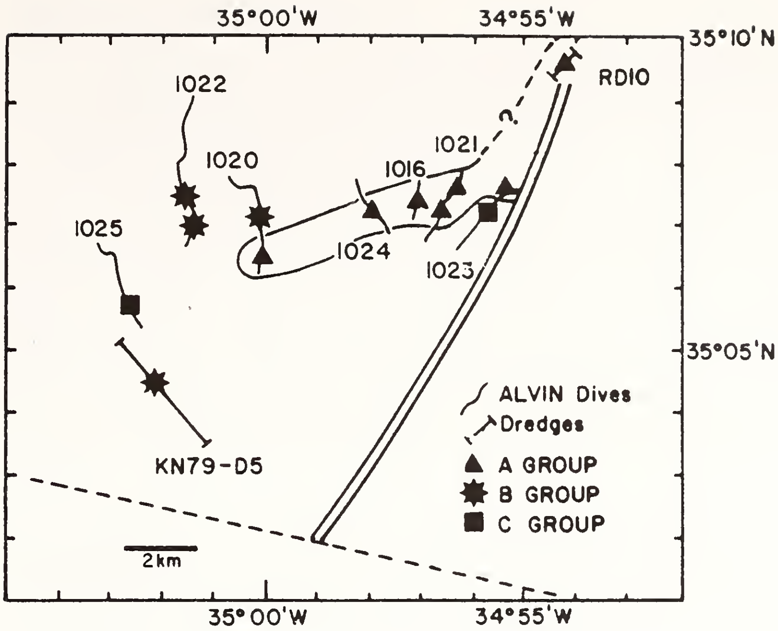


Fig. 19. Region of intersection of the mid-Atlantic ridge (double line) and Oceanographic transform area (dashed line), showing locations of samples studied by DTM geochemist Steven Shirey and colleagues. The area of the Group A samples, which Shirey believes are derived ultimately from subcontinental material, is encircled. Samples were obtained by the submersible Alvin (dive tracks shown). Shirey's study demonstrates how erupted materials contain chemical and isotopic clues to deeper earth phenomena.

part of the lithosphere, to have been eroded from below. The result is important because, as Wetherill notes, it indicates that subcontinental lithosphere, although durable, can be removed and mixed in with the other "flotsam and jetsam" that increasingly seem to characterize the suboceanic mantle.

The ability of passive heterogeneities to survive in the convecting mantle is poorly understood by geodynamicists. The Oceanographer transform area appears to provide an example of such survivability. If convection is an effective mixer of the mantle, as is generally supposed, then some mechanism for the recent transfer of old subcontinental mantle is needed to explain how the isotopic age of the heterogeneity could exceed its expected lifetime in the convecting mantle.

The detailed approach exemplified in this study is important to an understanding of the deeper crustal and mantle processes controlling the chemistry of materials erupted at the surface. Shirey writes that "an understanding of heterogeneity on the small scale is fundamental to the interpretation of heterogeneity on larger scales."

The Crust-Mantle Transition. The geochemical characteristics of the crust-mantle boundary, along with the petrologic compositions either side of it, are poorly known. Direct study of the transition region requires access to material once buried at depths as great as

30–60 km. Such material is found at the surface in a few places, where forces resulting from plate motion have overturned parts of the lithosphere, as in the Alps. More-widespread samples from the lower crust and upper mantle, however, are available only as fragments (xenoliths) incorporated during the ascent of some alkalic magmas. Potassium-rich volcanic rocks commonly carry such xenoliths, and because these lavas move quickly to the surface, the fragments remain intact, equilibrate minimally with the host magma, and can be studied in detail. The Four Corners area of the southwestern United States 25–50 million years ago underwent a period of potassic volcanism.

DTM postdoctoral fellow Sonia Esperança has studied a series of xenolith samples from the Camp Creek locality in central Arizona. She hoped to obtain evidence as to the timing and nature of the igneous and metamorphic processes modifying the crust just above the mantle transition.

She found that although the xenoliths vary substantially in bulk composition, they point toward a lower-crustal assemblage largely consistent with seismic data. Her petrographic analyses and isotope and trace-element geochemistry reveal a complex history of enrichment and depletion at various times. The xenoliths are from fundamentally ancient rocks—about 2 billion years in age—differing from more-surficial rocks in chemical and mineralogical compositions. The xenoliths exhibit the effects of complex and continuing metamorphic processes, such as dehydration, extraction of rubidium, and a lowering in the ratio of light-rare-earth to middle-rare-earth elements. The work demonstrates that the lower crust sampled is basaltic in composition and that it has undergone several episodes of re-equilibration with percolating magmas and fluids in the past two billion years.

Evolution of the Continents. The extremely dynamic state of the early Earth has resulted in the loss of direct evidence from when the Earth formed, 4.5 billion years ago, to when the ancient continental nuclei, or cratons, formed, about 3.5 billion years ago. Obtaining and interpreting the geological record associated with craton formation are therefore of special importance not only intrinsically but also for evidence of events during the earlier 1 billion years of earth history.

Staff member Richard Carlson of DTM and visiting investigator Allan H. Wilson of the University of Natal are applying isotope geochemical techniques to material of the Kaapvaal craton in southern Africa. They show that the craton grew during the period from 3.5 to 3.2 billion years ago by the serial addition of greenstone belts to the south, culminating in the Nondweni sequence of volcanic rocks. They draw the important conclusion that these greenstone belts formed near the old continental core, if not

actually right on its margin, by processes very similar to continental-margin (i.e., subduction-zone-related) volcanism today.

These "addition" events, however, are distinct from the earlier events forming the craton's core rocks—the Ancient Gneiss Complex. Geochemical and isotopic characteristics of core material suggest that the core's origin is not related to subduction-caused volcanism, but rather to the rapid recycling and remelting of mafic and ultramafic volcanic rocks. Perhaps the best modern analogy would be a place like Iceland, where some 10-15% of the exposed rocks are "granite"—probably originating by remelting of hydrated mafic rocks in the Iceland volcanic pile.

The work of Carlson and Wilson supports the following model for the origin and evolution of the Kaapvaal craton: (1) production of large volumes of basaltic-to-komatiitic lavas perhaps over a large mantle plume, (2) contemporaneous hydration and remelting of mafic rocks to form a significant volume of granitoid rocks, which ultimately cause the volcanic pile to become buoyant enough to resist subduction, and (3) initiation of subduction along the borders of this continental core, leading to its subsequent growth over several hundred million years by processes similar to those now operating in the Andes.

Experimental Studies on Crust and Mantle Processes

> It is imperative that laboratory study undertaken in the service of the various branches of geology should become commensurate in scope with the geological problems which it seeks to solve.
>
> Arthur L. Day, Director
> Geophysical Laboratory
> *Year Book 9* (1910)

Arthur Day, the founding director of the Geophysical Laboratory, believed that the Laboratory should take strong leadership in converting geology from a descriptive to a quantitative science. Day envisioned that the Laboratory should take possession of the middle ground between geology on the one hand and physics and chemistry on the other; an analogy existed among the astrophysicists, who had recently brought the methods of physics to the study of the stars.

Today, the hallmark of the Geophysical Laboratory remains in experimental investigation. The range of topics is wide, reflecting the varied interests of the staff and the common goal of understanding fundamental earth processes. Although experimental work is often designed to complement theoretical and field evidence, every study in large part entails the acquisition or application of laboratory data.

Formation of Layered Intrusions and Flood Basalts. T. Neil Irvine of the Geophysical Laboratory has for many years focused his attention on layered igneous intrusions—chamberlike bodies of rock formed by the cooling of magma at relatively shallow depths in the continental crust. In his recent research he has studied the mechanisms whereby such magmas have been produced in the upper mantle and emplaced in the crust. His present analysis combines insights from his laboratory studies on density currents in fluid media with geological and geophysical observations of a large region surrounding the Muskox Intrusion in northwestern Canada (Fig. 20).

The Muskox Intrusion has been exposed at the surface by erosion over an area measuring about 125 × 12 kilometers, where it is seen to occupy a troughlike chamber. Gravity data indicate that it extends northwest from this area, beneath its roof rocks and younger cover, for another 300 kilometers (along the line *AB* on Fig. 20). The Intrusion is closely associated with the Coppermine River flood basaltic lavas, which extend across it and have an estimated volume of 140,000 cubic kilometers. It is also affiliated with the Mackenzie diabase dike swarm, which consists of thousands of basaltic dikes, typically a few meters to tens of meters wide and several kilometers long, extending like a fan to the southeast across a major part of northern Canada.

Irvine proposes that these magmas were the joint products of a large, hot, upwelling gravity current that flowed southward in the upper mantle beneath the Coppermine region, as part of the Precambrian mantle convection system. A map of the apparent extent of the current is shown in Fig. 20; a block diagram illustrating its probable shape and the inferred nature of the processes specifically involved in formation of the Muskox Intrusion appears in Fig. 21.

By Irvine's analysis, the mantle current originated several hundred kilometers to the northeast of Muskox in a region where other workers have proposed that a new ocean basin was opened by plate tectonic processes about 1.2 billion years ago. From there, the current flowed as a hot, plastic mass on an arcuate path extending beneath Muskox and expanding to the southeast on the trend of the Mackenzie dike swarm (see expanding arcs #1–7, Fig. 20). The magmas were melted within the hot current in response to the release of pressure accompanying its upwelling.

A key aspect of Irvine's concept is that Muskox and Coppermine River magmas were fed from specific "magma release centers" located at the apexes of clefts in the hot-current front (see the clefts in arcs #3, 4, and 5 in Fig. 20, and the magma release center in Fig. 21). Such clefts are a common feature of laboratory density currents, where they form because some of the dense mobile material invaded by the upwelling current is initially trapped above

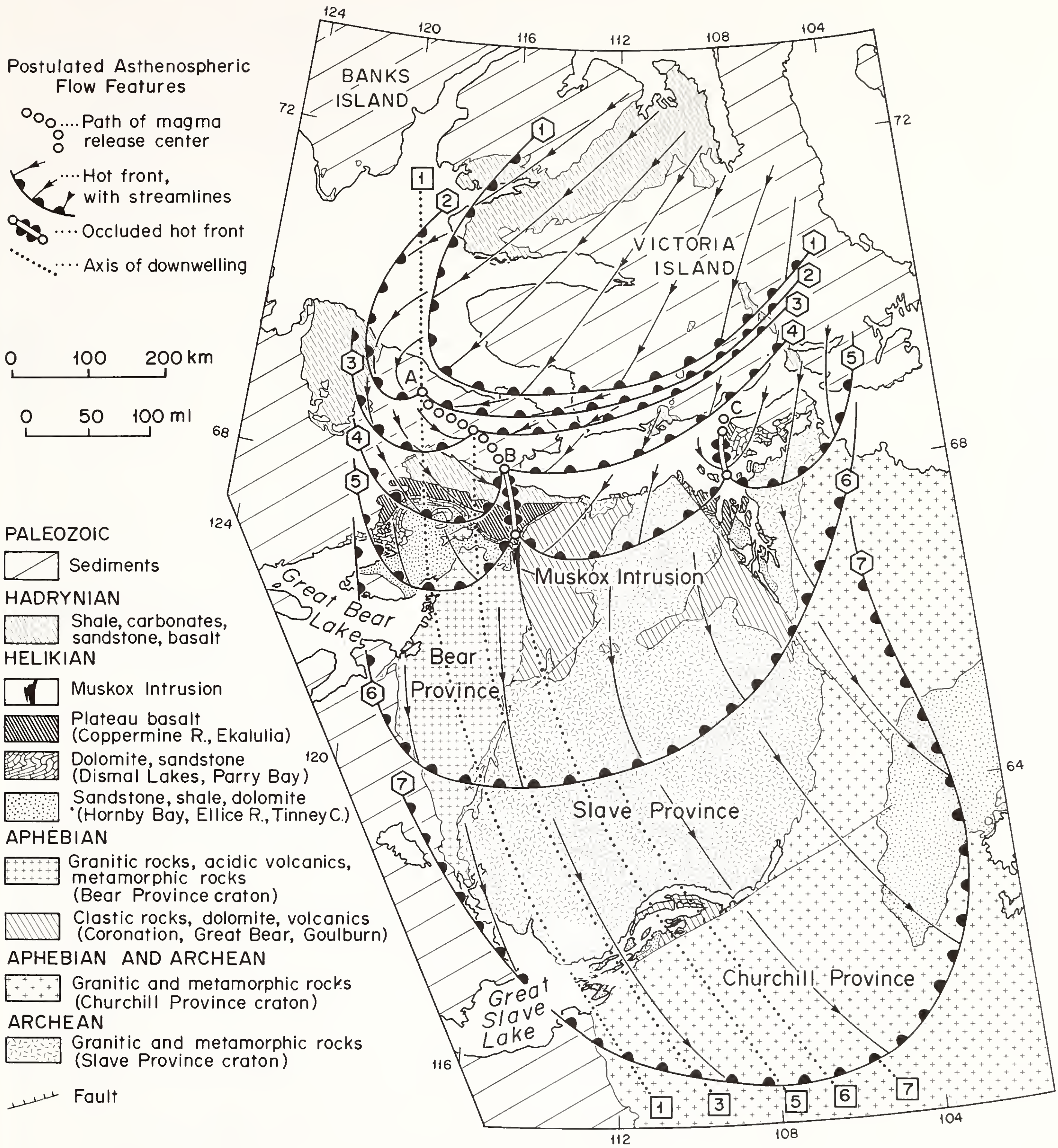


Fig. 20. Map of the regional geology around the Muskox Intrusion in the Canadian Northwest Territories. The Intrusion is exposed by erosion in the labeled area (125 × 12 km) shown in black; its subsurface part is defined by a large gravity anomaly extending to the northwest through *B* to *A*. The flow pattern of the upper mantle current proposed by T. Neil Irvine of the Geophysical Laboratory is shown by the succession of fronts numbered 1 to 7. He concludes that after yielding Muskox and the Coppermine River basalts, the current swept on to the southeast beneath the Slave and Churchill provinces and produced the Mackenzie diabase dike swarm (not shown). All these events occurred 1.2 billion years ago.

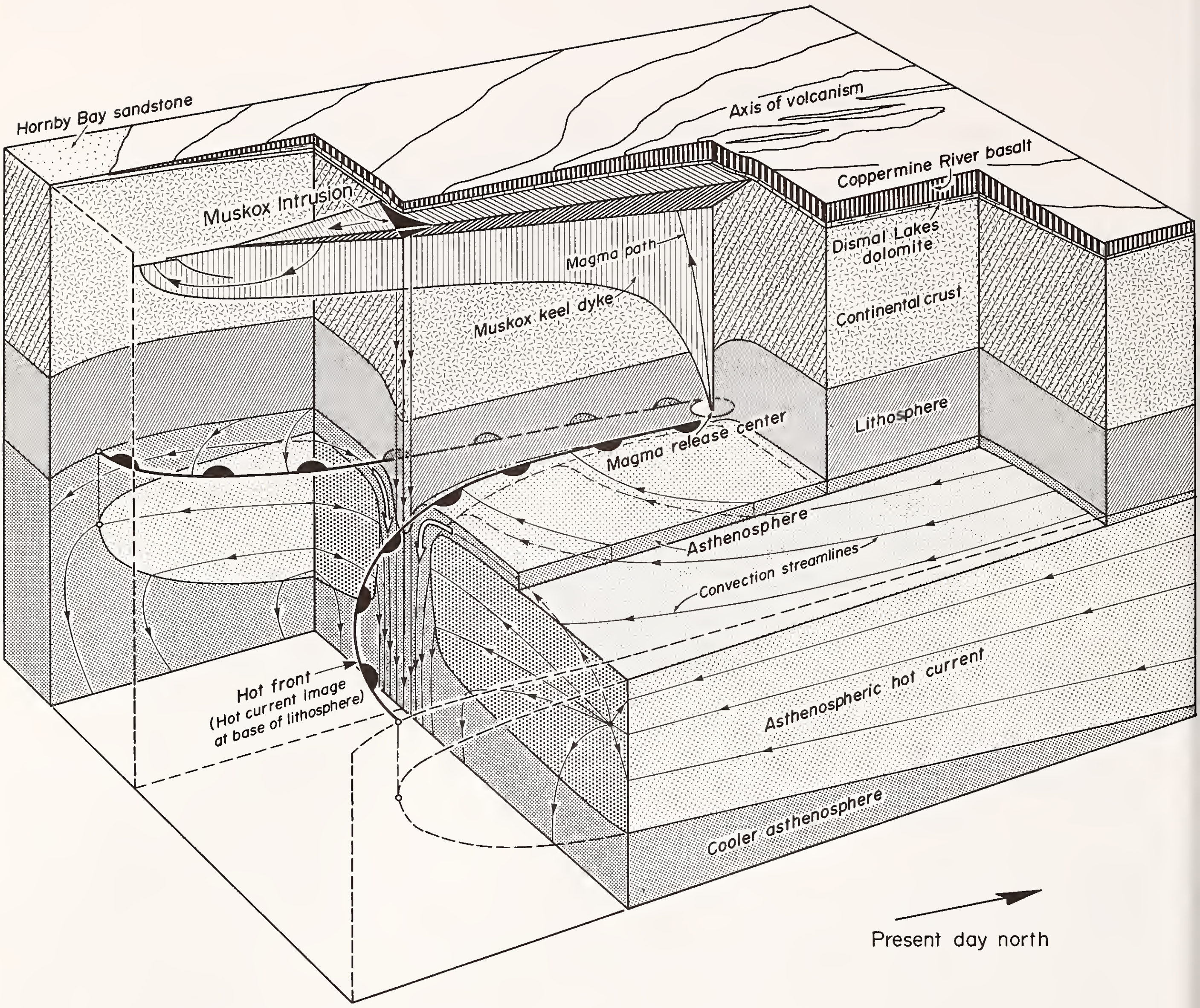


Fig. 21. Block diagram illustrating Irvine's concept of how the Muskox Intrusion was emplaced. The magma is produced by melting in the asthenospheric hot current and is fed vertically to the intrusion from the magma release center (see text). Downwarping of the lithosphere and crust into the cleft in the hot front opens the space for the intrusion.

the current in a gravitationally unstable position. The clefts then develop as escape routes through which this material can drain downward. Irvine suggests that such downwelling along a cleft beneath Muskox caused localized downwarping of the continental lithosphere and crust immediately above, ultimately producing the troughlike chamber of the intrusion by pulling down its floor (see Fig. 21). Concurrently, magma rose nearly vertically from the magma release center at the cleft apex and entered the intrusion, where it then flowed southward to fill the space being created by the downwarping.

Irvine points out that a major gravity anomaly along the line *AB* may be regarded as a record of the path of the magma release center beneath the continental crust. However, this trend probably

reflects not just the motion of the center, but also a southwesterly shifting of the lithosphere caused by the westward expansion and push of the current. This interpretation is consistent with paleomagnetic data from the intrusion, flows, and dikes. These data indicate that the whole terrain was rotated 28 degrees counterclockwise relative to an equatorial paleomagnetic pole position during the general time period when the rocks were formed.

These concepts may have far-reaching significance because they are potentially applicable not only to other layered intrusions but also to other occurrences of flood basalt and other diabasic and basaltic dike swarms.

Understanding Regional Metamorphism. Among petrologists interested in the origins of rocks, there have been growing efforts to understand the physics of earth processes. One important question is whether the heat that causes metamorphism—the alteration of subsurface rocks to new mineral forms and textures—is transferred by conduction or by convection. (Is the thermal energy for metamorphism conducted through the atoms and molecules of the surrounding rock, or is it carried in the movement of hot, convecting fluids?)

Approaches to this fundamental question require a thorough grounding in petrology and geochemistry along with knowledge of geophysics and applied mathematics. The Geophysical Laboratory has assembled a group of investigators together possessing the needed breadth of expertise.

Past theories of metamorphism are based on the assumption that heat transfer takes place primarily by conduction. Early thermal models rested on the wide belief that rocks at depths below 10 kilometers were essentially impermeable to the transfer of material. Laboratory experiments on rocks recovered from drill cores showed low permeabilities. The experiments, however, did not bear on dynamical processes that might enhance permeability in a region, such as tectonic fracturing or devolatilization. However, the recognition of anomalous thermal structures, such as the metamorphic hot spots recently identified by Geophysical Laboratory postdoctoral fellow C. Page Chamberlain, has led to reappraisals of the heat conduction hypothesis.

Chamberlain and colleagues have embarked on a study of fossil hydrothermal systems—networks of quartz-graphite veins at high pressure and temperature—in regional metamorphic belts. The vein networks are interesting because, as Chamberlain and staff member Douglas Rumble have shown, they are located in the heart of Chamberlain's metamorphic hot spots. Thus there is coincidence in location of anomalously high heat flow (the hot spots) and high fluid flow (the veins). Chamberlain and Rumble are investigating whether there is a cause-effect relationship between high fluid flow and high heat flow. If a link can be shown, a new generation of

thermal models will be required to take into account convective as well as conductive heat transport in metamorphism.

The research has proceeded on two lines. One is to establish the relative geologic age of vein networks in relation to the time of metamorphism by searching for evidence of chemical and isotopic interactions between veins and their surrounding metamorphic wall rocks. The other is to measure directly radiometric ages of vein minerals for comparison with the age of metamorphism. If it can be shown that the veins and metamorphic hot spots were contemporaneous, then the likelihood of a cause-and-effect relation would become strong.

Chamberlain, Rumble, and staff member Thomas Hoering have carried out chemical and stable isotopic analyses of vein minerals and surrounding wall rocks. They have shown that graphic-quartz veins in the Bristol, New Hampshire, hot spot are surrounded by a halo of oxygen isotopic alteration to a distance of five centimeters into the wall rock. It appears likely that this isotope exchange took place during metamorphism, a conclusion strongly supported by the observed lack of mineralogical alteration of cordierite-bearing wall rocks.

Rumble and postdoctoral fellow Russell Hemley are employing the laser micro-Raman spectrometer seeking evidence of vein-wall interactions. Analyses of ancient fluids trapped in veins and of those preserved in wall rocks will test whether vein formation and metamorphism took place simultaneously. (Semi-quantitative analyses of fluid inclusions in veins and wall rocks are possible for the species H_2O, CO_2, CH_4, CO, H_2, and N_2.)

Barbara Barreiro, a recent fellow at DTM and now at Dartmouth College, is measuring radiometric ages of vein minerals. She has analyzed U and Pb isotopes in zircons with euhedral overgrowths. Her preliminary results give an approximate age of 360 million years, in agreement with the generally accepted Devonian age of metamorphism in New England.

Thus evidence continues to accumulate suggesting that convective heat transfer has played an important role in metamorphism.

Kinetic Modeling of Fundamental Geological Processes. It should be possible to formulate quantitative models of fundamental earth processes. Such models, developed for the kinetic (i.e., the time-dependent, as opposed to the equilibrium) properties, would incorporate coupled processes, such as geochemical reaction kinetics and modes of heat and mass transfer. Besides their value for comprehending the larger dynamic evolution of crust and mantle, such models should be useful as practical, predictive tools. For example, if a kinetic pathway—how a system reached its present state—is shown to correlate with a particular magmatic or hydrothermal ore deposit, then field evidence of the same pathway elsewhere could provide guidance for future exploration. The

current research of W. M. Keck Research Scholar Greg Muncill, who has worked at the Geophysical Laboratory since 1983, has been directed toward development of such coupled kinetic models.

In one endeavor, Muncill is developing a relatively simple model describing crystal growth rates of minerals from silicate melts. He is testing the model by performing laboratory growth-rate studies on synthetic silicate melt systems. The experimentally derived growth rates are compared with rates predicted by the model, and if required, the model is then refined. The initial experiments (on a simplified system approximating a granite in composition) are encouraging. Simultaneously, Muncill is studying the phase compositions in the synthetic systems. (Knowledge of the equilibrium properties of systems is essential for establishing the direction of the reactions and the magnitude of "driving force" involved.) When combined with heat-transfer and mass-transfer models, the growth-rate model can be used in studying the evolution of natural magmatic systems.

In another venture, Muncill and postdoctoral fellow Donald Dingwell are investigating the factors controlling dissolution rates of minerals in relatively simple, anhydrous silicate melts. An early conclusion is that dissolution rates in anhydrous granitic-type melts are much slower than rates determined by other workers for anhydrous basaltic-type melts. The investigators believe that volatiles dissolved in the melts will have a large effect on rates, especially in granitic systems, and they plan further experiments with volatile-bearing (H_2O and F) melts.

Muncill and Chamberlain are using a model for the homogenization of concentration gradients in minerals to indicate the past cooling rates after peak metamorphism in a New England metamorphic region. The investigators plan to compare the indicated rates with cooling rates derived independently from geophysical models of heat flow. Muncill and Chamberlain envision that the procedure will enable them to develop the homogenization model into another tool for interpreting the thermal history of complex metamorphic regions.

Muncill conceives that the information concerning the various independent processes can eventually be integrated into coupled, system-wide models, thereby facilitating understanding of the processes in the evolution of magmatic systems and their interrelations with the local environment.

Structure and Property in Silicate Melts: Solubility Mechanisms. Traditionally, earth scientists seeking to understand magmatic processes obtain experimental data on the pressure-temperature-composition relations governing which minerals will crystallize from given magmatic liquids. They seek the distribution of major, minor, and trace elements among liquids, minerals, and fluids, and various physical properties of liquids and mineral-liquid mixtures.

These physical properties include viscosity, compressibility, electrical and thermal conductivity, and element diffusivity.

A different, more fundamental approach is being taken by investigators Bjørn Mysen, David Virgo, and co-workers at the Geophysical Laboratory. They are conducting experimental studies of silicate melt structure, largely to ascertain relationships between melt structure and the physical properties. By this approach they expect to predict accurately physical properties over the wide range of compositions, temperatures, and pressures where magmatic liquids form, evolve, and crystallize.

The most important structural entity in natural magmatic liquids is the three-dimensional network unit, where all oxygens are bonded to two neighboring tetrahedrally coordinated cations. In one large sample of Cenozoic extrusive rocks of known bulk composition, from 66% to 100% of the network units are three-dimensional. Figure 22, on next page, shows how the property of molar volume, which is closely related to melt density, and the viscosity are positively correlated with the concentrations of three-dimensional network units in natural magmatic liquids.

Mysen, Virgo, and colleagues have turned their attention to volatile components, such as water and fluorine, which are the most important volatile constituents of igneous rock. One effect of volatiles in magma is seen in volcanic eruptions, where water-rich magmas erupt violently; thus along continental margins, where the source regions of magma are particularly rich in volatiles, volcanic eruptions are typically highly explosive and often destructive. This behavior results from the large difference in partial molar volume of H_2O in solution and the molar volume of H_2O in a separate fluid phase at the same pressure and temperature.

Such aqueous fluids are often efficient solvents of geochemically (and sometimes economically) important elements. It is therefore important to describe the partitioning of elements between the magmatic liquids and the coexisting aqueous fluids at magmatic temperatures and pressures.

Furthermore, dissolved water or fluorine profoundly affect the structure of a magmatic liquid. As water or fluorine is dissolved in a melt that originally contained 100% three-dimensional network units, the melt structure is depolymerized—i.e., broken up into smaller units, with many nonbridging oxygens. (A nonbridging oxygen is bonded to only one tetrahedrally coordinated cation.) Thus a measure of the degree of melt polymerization is the proportion of nonbridging oxygens per tetrahedrally coordinated cations, or NBO/T. The curves in Fig. 23 are experimental results showing how depolymerization (NBO/T) increases with increase in water or fluorine content. (Depolymerization is also seen to increase with decrease in Al content in melts of equal volatile content.) Experimental results showing relationships between NBO/T and melt viscosity are plotted in Fig. 24. Because water or fluorine in

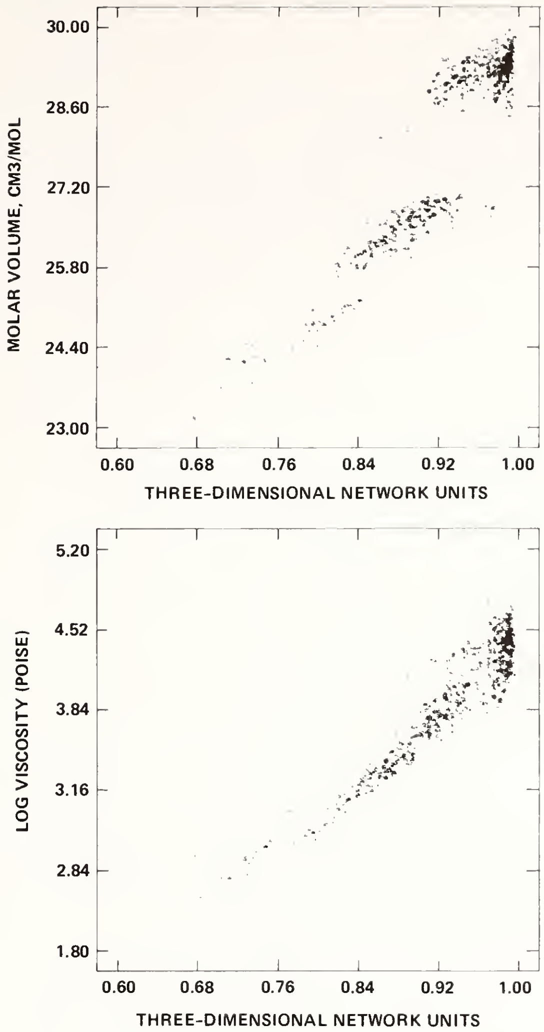


Fig. 22. Bjørn Mysen, David Virgo, and colleagues at the Geophysical Laboratory have for several years studied network structure in melts; a foremost objective is to use structural information to predict magmatic liquid properties over a wide range of compositions, pressures, and temperatures.

The above diagrams show relationships between the proportion of three-dimensional network units in the melt structure, and molar volume (a property closely related to density) and viscosity. (Calculated from the chemical compositions of 705 Cenozoic rocks, rockfile RKNFSYS; see Chayes, *Year Book 74*, 550–551. The rock types included are rhyolite, dacite, andesite, and tholeiite.)

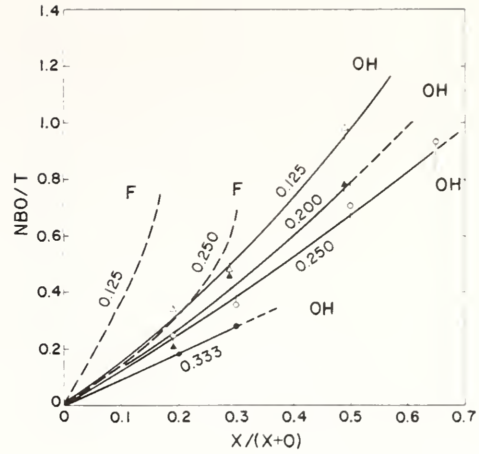


Fig. 23. Experimental data by Mysen *et al.* showing *NBO/T* vs. volatile content of water- and fluorine-bearing melts on the join SiO_2-$NaAlO_2$. Curves labeled *OH* represent hydrous melts, volatile content expressed as OH/(OH + O). Dashed curves labeled *F* represent fluorine-bearing melts, volatile content expressed as F/(F + O). The numbers shown on each curve are values of bulk composition in Al/(Al + Si). Depolymerization (*NBO/T*) is seen to increase with increasing volatile content. Also, for a given volatile concentration, higher Al content will result in decreased *NBO/T*.

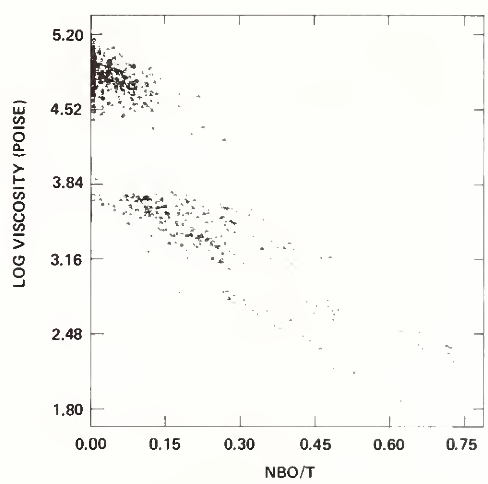


Fig. 24. Viscosity as a function of degree of polymerization (*NBO/T*) of the melts. (Samples are the same ones shown in Fig. 22.)

solution affects melt structure, any melt property related to structure is also a function of water or fluorine content.

A detailed understanding at the structural level of the solubility mechanisms of water and fluorine in natural magmatic liquids can provide a basis for understanding the relationship between volatile content and viscosity. Solution of water or fluorine in magmatic liquids takes place by interaction between OH^- or F^- groups and

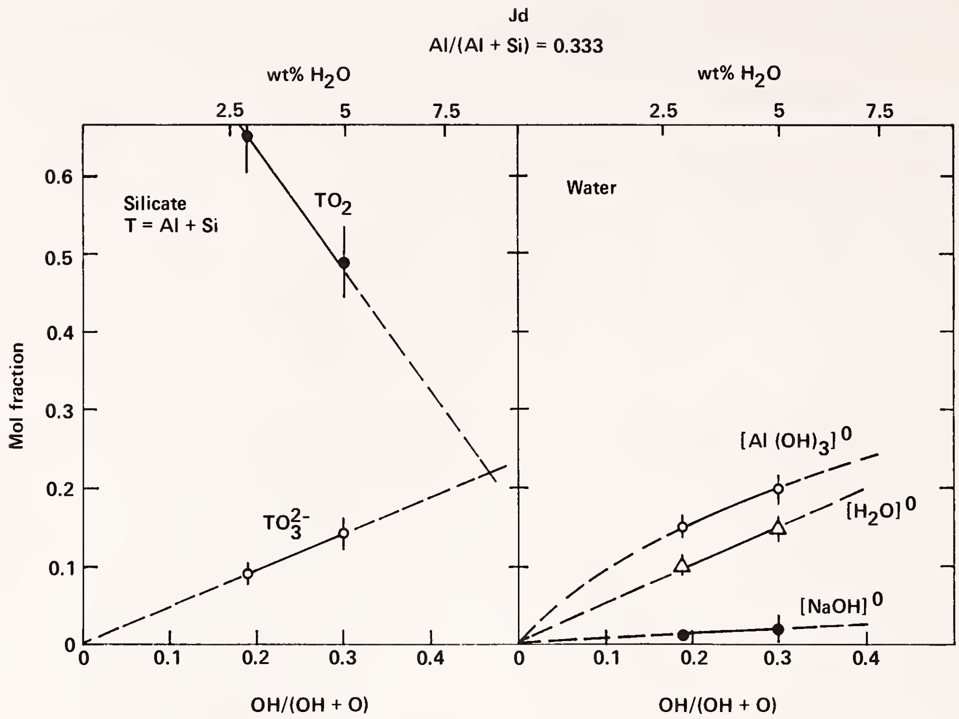


Fig. 25. Experimental data for a melt of Jd composition ($NaAlSi_2O_6$), showing how melt structure varies with volatile content. At left, with increasing presence of H_2O, or OH/(OH + O), the proportion of the three-dimensional-network form $(Al,Si)O_2$ oxide is reduced and the depolymerized $(Al,Si)O_3{}^{2-}$ form is increased. (In the diagram, T = Al + Si.) At right, the proportion of Al complexes in water dissolved in the magmatic liquid is seen to increase substantially with increasing presence of H_2O.

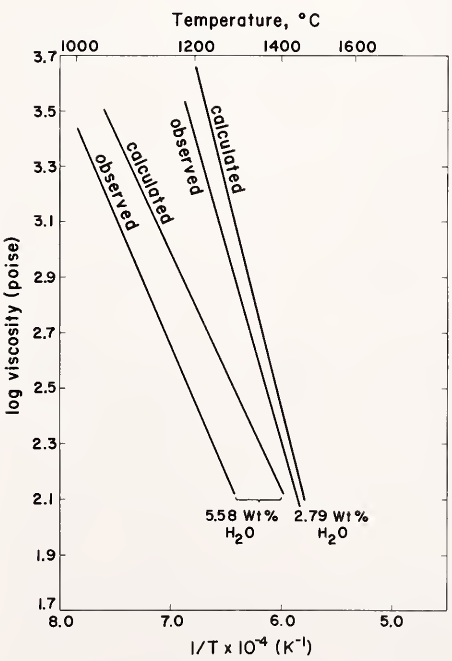


Fig. 26. Values of viscosity calculated from solubility mechanisms data by Mysen *et al.* and observed viscosities, plotted against temperature, water contents shown. (See text).

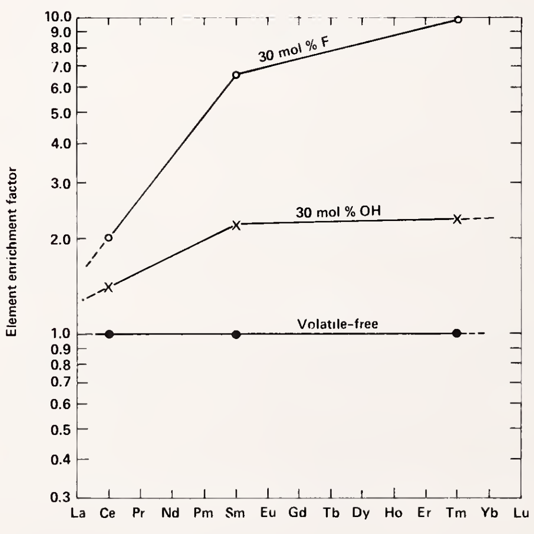


Fig. 27. Effect of water and fluorine on the enrichment of rare earth elements in magmatic liquids (in equilibrium with a hypothetic mineral phase with partition coefficients equal to 1 for volatile-free melts). The data are from calculations by Mysen *et al.*, based on their knowledge of melt structure.

metal cations in the liquids. The most important complexes thus formed involve aluminum and sodium. The Geophysical Laboratory investigators have experimentally studied the proportions of such complexes as well as the overall effects on melt structure as a function of bulk composition. An example of their results is shown in the drawing, Fig. 25.

From the established relations between structure, property, and dissolved water and fluorine content, Mysen *et al.* used their data on solubility mechanisms to calculate the viscosities of aluminosilicate melts at given H_2O content. The resulting values accorded well with experimental measurements of viscosity to within 5%—an amount less than the uncertainty in the measurements (Fig. 26). The data can also be used to predict structural changes in liquids and, therefore, changes in the kinds of minerals likely to crystallize from the liquids as a function of the volatile component. Increase in fluorine content enhances the probability of crystallization of aluminum-deficient minerals (quartz and tridymite); increase in water content enhances crystallization of Al-rich minerals. Thus in natural magmatic systems, residual magma from water-rich magmatic systems is more aluminous than that from fluorine-rich systems.

Structural changes in liquids resulting from dissolved volatiles also alter partition coefficients between melts and minerals of geochemically important trace elements—the rare earth elements, for example, which are considered particularly sensitive indicators of the petrogenetic histories of rocks. It can be seen in Fig. 27 that with increasing water or fluorine contents, the rare earth element patterns in the volatile-bearing liquids coexisting with crystals change rapidly. The effect is significantly more pronounced for fluorine-bearing than for water-bearing melts. Whereas traditionally the changes in rare earth element patterns would be ascribed to changes in liquidus mineralogy of the magma, the results summarized in the drawing show that the volatile contents of the magmatic liquids may have a similiar effect. These inferences can be made because the details of the solubility mechanisms of fluorine and water have been established, and the relationships between rare earth element partitioning and melt structure have been determined.

The results of Mysen *et al.* for the first time show that the physical and chemical properties of magmatic liquids required to characterize magmatic processes can be described in terms of the structures of the liquids. Whereas in the past a painstaking effort was required to measure each property for each magma composition, the experimental and theoretical framework is now in place to predict accurately liquidus phase equilibria, element partitioning, viscosity, and density in magmatic liquids.

The Inverted Telescope Idea

The pioneering seismologist R. D. Oldham wrote in 1906 that the goal of seismological research is "to see into the earth and to determine its nature with as great a certainty... as if we could drive a tunnel through it and take samples of the matter passed through."* Eighty years later, seismology is on the threshold of realizing that goal. New initiatives are capitalizing on remarkable technological breakthroughs in low-power digital recording, which together with advanced data processing methods provide the essential elements for constructing a mobile "inverted telescope" for probing the Earth's interior in geological detail.

The idea exploits the concept of full-wavefield recording and analysis, in contrast to the older approach of ray-tracing distinct seismic phases. Seismic wavefields are observed using an array of seismic recorders positioned in an appropriate pattern on the surface. The wavefields, which are superpositions of compressional and shear waves generated artificially or naturally, are exceedingly complex and perhaps beyond full analysis. New digital techniques, however, appear to make possible the identification of major features of wavefields and the relationship of such features to layering or other heterogeneities in the Earth. The concept of seismic wavefield imaging is rather similar to that of holography or tomography using electromagnetic waves—i.e., to use all the information contained in a wavefield to produce three-dimensional images of the contrasting seismic velocity structure in the Earth's interior. The velocity structure, in turn, can be interpreted in geological terms.

In theory, seismic illumination of structures within the Earth can be achieved by several methods. But in actuality, the only true wavefield imaging generally practiced is reflection imaging using waves generated at the surface—a method developed for oil exploration and largely limited to depths of 15 km or less. A major obstacle to deeper imaging is the lack of adequate instrumentation; particularly needed are "smart," microprocessor-based portable instruments capable of continuously examining incoming seismic signals and recording only actual earthquake events. The feasibility of such instruments is undoubted, however, and their development is an important part of current activity in the inverted-telescope project.

Another handicap to deeper studies is the limited energy available when using artificial sources (i.e., explosions) for generating seismic energy for reflection profiling. Some years ago, scientists essentially

*R. D. Oldham, Constitution of the interior of the Earth, *Quart. J. Geol. Soc. London 62*, 456–473, 1906.

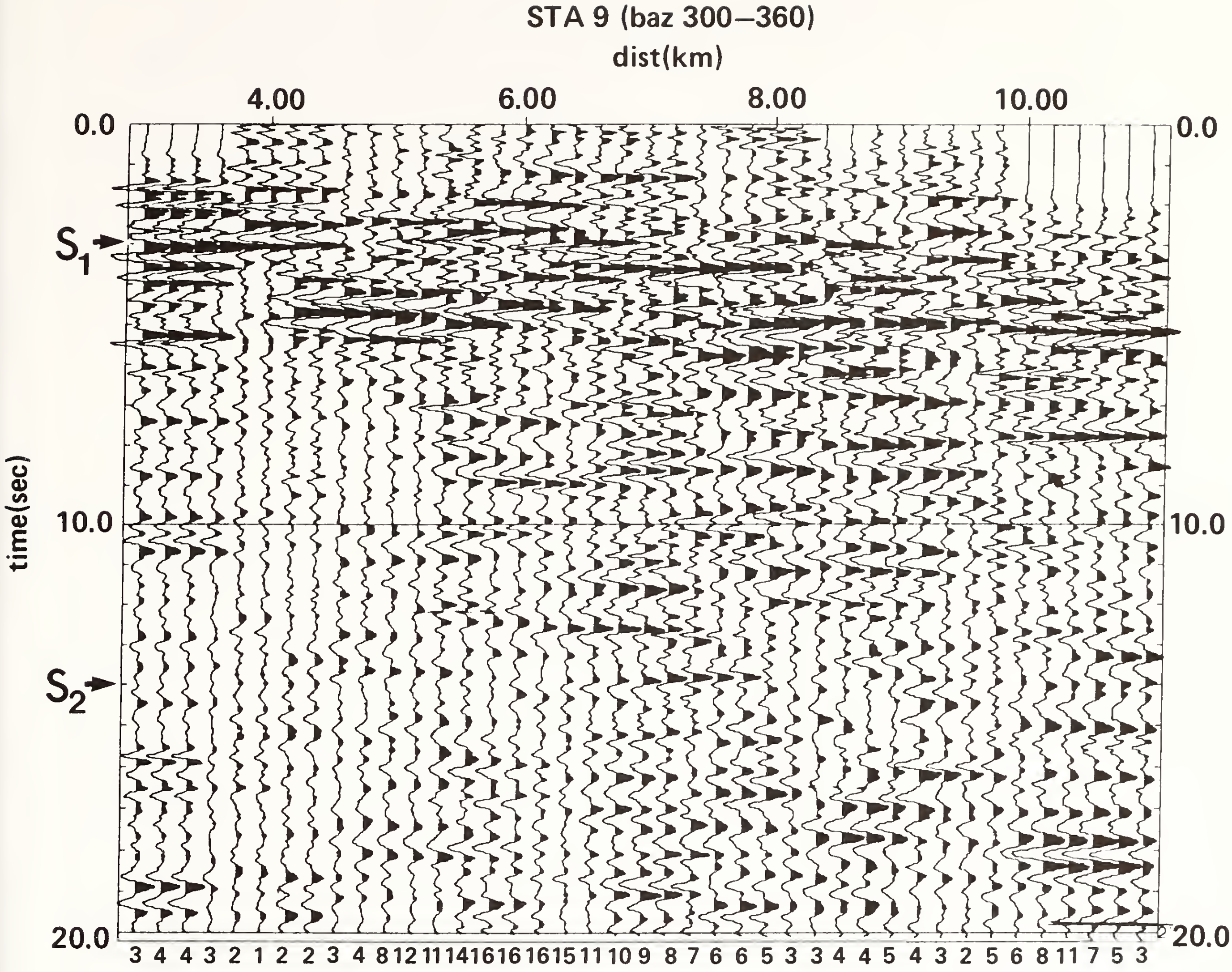


Fig. 28. Scientists are working toward a capability for obtaining high-resolution images of the Earth's crust and upper mantle by analyzing digital seismograms of microearthquakes recorded on dense local networks. The possibilities in the method are shown in a recent analysis by David James and Timothy Clarke of DTM, and their collaborators at the University of Wisconsin. Shown here, seismic tracings from microearthquake events recorded at one of the stations arrayed at Borah Peak, Idaho, following the 1983 major earthquake. Data from the different sources are normalized to common depth and magnitude, and are then stacked in the fashion shown here to provide data redundancy thereby enhancing the true signal. The traces are stacked at distance intervals of 0.20 km in a northwesterly azimuth from the station. S_1 and S_2 indicate hypothetical model times for reflectors at 18-km and 40-km depths. Zones of strong reflection can be seen at about 19 km and 25 km. (Each trace represents a sum of up to 16 individual seismograms, as indicated by the numbers at the foot. For convenience in the display, zero time is arbitrarily set to about 4 seconds after normalized origin time.)

gave up on using natural earthquakes as sources for detailed crustal studies because of uncertainties in event locations and origin times. Controlled sources therefore became the fashion, not just for oil exploration but for most scientific investigations of crustal structure.

In a pilot study aimed at exploring the innovative use of earthquake sources for imaging of deeper regions, DTM staff member David James has joined with Professor Robert P. Meyer and his students at the University of Wisconsin. (Wisconsin is one of the few academic institutions with a sizeable complement of portable digital seismographs.) The investigators employed data obtained from a small array of Wisconsin seismographs, which had been deployed over a region of aftershocks following a 1983 major earthquake at Borah Peak, Idaho. Using numerical techniques now possible because of recent advances in affordable computer power, the investigators succeeded in combining and correlating data from many seismic events. The first results revealed the existence of a prominent reflecting horizon at a depth of about 19 km; less-prominent reflections were seen from 25 km. Some of the reflections are continuous over the area of the array.

This first experiment, which used a rather small seismic array but data from multiple sources, demonstrated the feasibility of array seismology for high-resolution imaging of the Earth's crust and indicated its potential future importance (see Fig. 28).

Biogeochemistry

Research on the Earth's biochemical processes at the Geophysical Laboratory is opening the way for useful applications in the plant sciences, in paleontology, in the study of marine systems, and in the study of crude oils and shales. A venture in the plant sciences, in partnership with scientists of the Department of Plant Biology, has been discussed earlier (see p. 12). Other enterprises, discussed below, provide a cross-section of leading work in this rich subdiscipline.

Paleodiets from Stable Isotope Studies. Research by Geophysical Laboratory investigators P. Edgar Hare, Marilyn Fogel (formerly Estep), Thomas Hoering, and Thomas Stafford has shown that the stable isotopes of nitrogen and carbon in the amino acids of animal proteins are related to diet. Half of the twenty amino acids in animal proteins cannot be synthesized by most animals and thus must ultimately be supplied by plant proteins in the diet. Most plant food proteins used by man are from plants using the C_3 photosynthetic pathway, such as wheat, barley, oats, and soybeans. Proteins from these plants are consistently lower in their $\delta^{13}C$ values than proteins from plants using the C_4 photosynthetic pathway. Corn and sugar cane are foods derived from C_4 plants and are around 12 parts per thousand heavier in $\delta^{13}C$ than are proteins derived from C_3 plants. A study of the bone collagen of American Indians, from archeological sites in the eastern United States, showed a marked increase in $\delta^{13}C$ 500–1,000 years ago, when corn

became a major dietary component.

The nitrogen stable isotopes do not similarly offer a means for distinguishing C_3 from C_4 plants, but they do offer evidence on the metabolic turnover of nitrogen in the synthesis of animal proteins. In experiments where animals were fed amino acids with known values of $\delta^{15}N$, Hare *et al.* and A. D. Mitchell of the U. S. Department of Agriculture discovered that the amino acid threonine has a unique stable isotope ratio. Whereas nitrogen used in synthesizing proteins from the other amino acids is drawn from a common pool of nitrogen in the animal, threonine cannot take nitrogen from this pool. Thus even in carnivores, the threonine's nitrogen must originally have been synthesized during plant biosynthesis.

From studies of collagen in bones of animals fed controlled diets, the investigators found that the threonine $\delta^{15}N$ is reduced 5–6 parts per thousand compared to the threonine of the diet. Thus, it appears that the amount of $\delta^{15}N$ depletion can provide an indication of the number of trophic levels through which the threonine has been cycled—a useful measure in studying food chains in different environments. A mixed herbivore and carnivore diet should yield intermediate ^{15}N threonine values reflecting the separate proportions of the diets and the trophic cycling.

The Delaware Estuary Project. Measurements of carbon and nitrogen isotopes in suspended particulate matter of the Delaware Estuary are contributing to understanding of this marine system. Geophysical Laboratory predoctoral fellow Luis Cifuentes, staff member Marilyn Fogel, and Jonathan Sharp of the University of Delaware are making such observations at different times and places in the estuary; they are comparing the resulting data with measurements of sediment load, organic material production, inorganic concentrations, and biomass. They are finding substantial variability in the isotope ratios with season and locality, and they are interpreting these variations (along with variations in the other measurements) in terms of seasonal and local phenomena.

Recent measurements of carbon and nitrogen isotopes in bottom sediments proved consistent with a mixing regime of terrestrial and marine sources. Carbon values near Wilmington, Delaware, indicated a large contribution by terrestrial plant material and sewage; values increased systematically toward the mouth of the estuary, indicating an increasing marine contribution. Nitrogen isotope measurements in bottom sediments mirrored the variations seen in suspended matter.

The group's work points to the profound influence of biological processes on isotope ratios. They have shown that among the factors strongly affecting isotopic abundances in the estuary are (1) the isotopic composition of inorganic and organic sources, and (2)

microbial processes, primarily nitrification and remineralization, which alter the isotopic composition of inorganic carbon and nitrogen available for phytoplankton uptake. The group is planning isotopic measurements of inorganic carbon and nitrogen in the estuary, in hopes of studying how variations in ratios may influence assimilation by organic matter.

Sedimentary Organic Matter. Recent experiments by Thomas Hoering follow a long tradition at the Geophysical Laboratory, where chemical processes seen in the Earth are studied under controlled laboratory conditions. The new experiments use the perspectives of modern synthetic organic chemistry to investigate how organic materials may have been transformed over geological time.

Molecules with long, straight chains of carbon atoms are common constituents of the organic matter in both living organisms and sedimentary rocks. (See carbon skeleton schematic of normal hexadecane, $C_{16}H_{34}$, in upper drawing, Fig. 29.) Less common but easily detectable are similar molecules having a single carbon branch point, where an additional carbon atom is attached to the chain. The fats and waxes of modern plants and animals contain molecules with the branching points primarily at carbons 2 and 3 (middle drawings, Fig. 29). But in current experiments, Hoering finds that the saturated hydrocarbons in ancient crude oils and shales have appreciable concentrations of molecules branching at carbons 4, 5, 6, etc. (bottom drawing, Fig. 29). Either ancient organisms had biosynthetic pathways such to produce molecules with these branch points or, as Hoering believes, extensive rearrangements have occurred in sediments to form these new molecules.

Hoering's observations are made possible by his discovery that a new molecular sieve, Silicalite, having pores 5.8 Angstrom units ($1 \text{ Å} = 10^{-10}$ meters) in diameter, selectively accommodates branched hydrocarbons. These compounds can be thus conveniently separated from the complex mixtures in petroleum. He then can perform quantitative analysis of branched hydrocarbons (having up to 30 carbon atoms) by means of new, bonded-phase, fused-silica gas chromatography columns and (for high-speed, selected ion monitoring) a quadrupole mass spectrometer.

Hoering postulates that a process occurring over long periods at ambient conditions in sedimentary organic matter is responsible for the rearrangements, or isomerization, from the original 2-methyl and 3-methyl forms to the present configurations. Such reactions are studied in synthetic organic chemistry, where isomerization is carried out with powerful acid catalysts, such as concentrated sulfuric acid or anhydrous aluminum chloride. Such reagents, however, are not likely to have been present geologically.

Certain clay minerals commonly found in host rocks can display

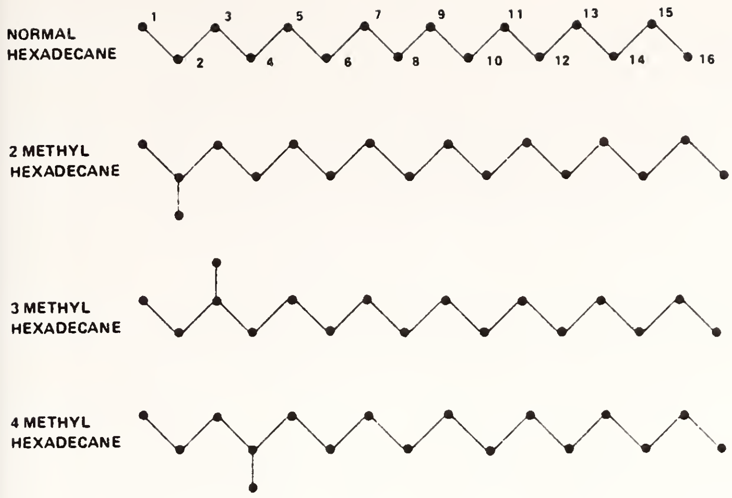


Fig. 29. Schematic representation of the carbon skeletons of linear and branched organic molecules. A carbon atom resides at each of the dots and forms four covalent, chemical bonds to other carbons (indicated by lines) or to hydrogen atoms (not shown). Note the possibility of chain branching where a carbon atom can be bonded to three other carbons.

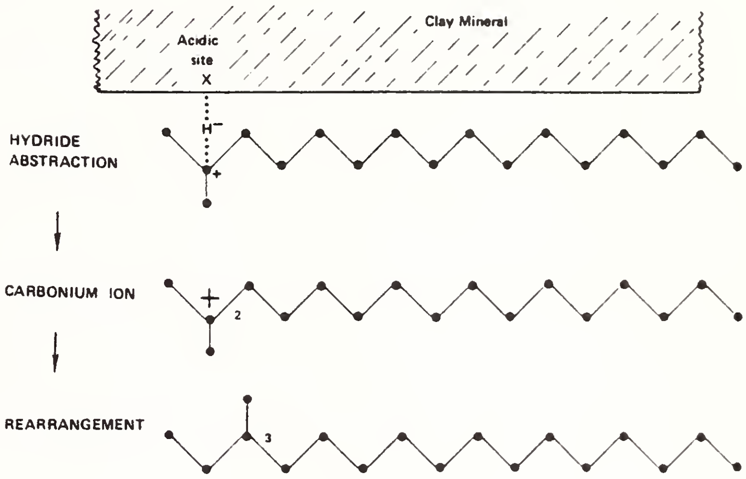


Fig. 30. A possible mechanism for rearrangement of branched hydrocarbons. A strongly acidic site in a clay matrix abstracts a hydride ion (H^-) from the branching point at number 2 carbon in the chain to form a positive center in the molecule (a carbonium ion). Such ions are extremely reactive and can rearrange to move the branch point down the chain.

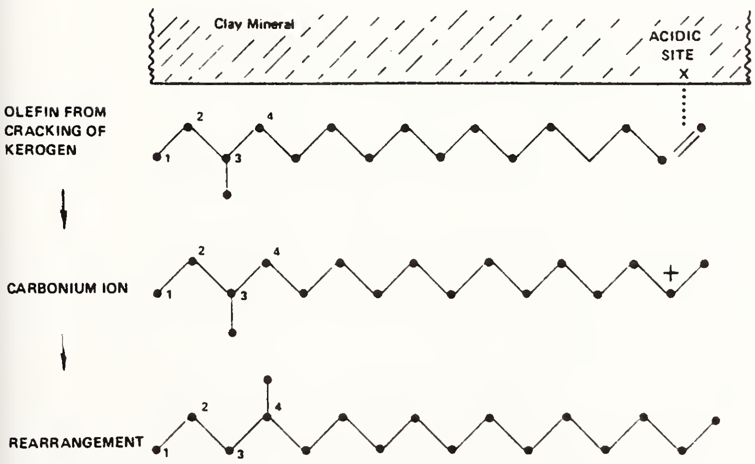


Fig. 31. An alternate, speculative mechanism, proposed by Thomas Hoering of the Geophysical Laboratory, for the rearrangement of branched hydrocarbons. Branched carbon structures, bonded into the solid kerogen of sedimentary organic matter, are thermally cracked off to yield an unsaturated organic molecule, called an olefin, having carbon-to-carbon double bonds. Such double bonds are known to accept a hydrogen ion (H^+) from acids to form carbonium ions, which can undergo carbon skeleton rearrangement.

acidic properties. (The H^+ ions responsible for the acidity in clay are believed to result from the dissociation of water molecules under the influence of exchangeable positive ions between the layers of alumino-silicate polyhedra.) Hoering is testing the possible role of acidic ions in clay as catalysts for isomerization in nature.

In his experiments, insoluble organic matter (kerogen) from Green River Oil Shale is heated for several days up to 300°C.

Green River Shale does not contain clay minerals but is mainly a poorly crystalline form of dolomite, $CaMg(CO_3)_2$. Dolomite does not promote acid catalysis and, as is expected, the hydrocarbons occurring naturally in this rock and during the artificial heating in the laboratory are mainly in the biologically inherited 2-methyl and 3-methyl forms. But when the naturally occurring clay mineral montmorillonite is added during the heating, the production of 4-, 5-, and 6-methyl isomers of hydrocarbons is definitely increased. This result is evidence favoring Hoering's hypothesis of acid catalysis.

It is also known that the presence of excess liquid water greatly diminishes the acid strength of water bound into the clay lattice. Hoering therefore heated the Green River Shale with montmorillonite in the presence of liquid water; the experiment yielded few of the 4-, 5-, and 6-methyl isomers, and therefore provided further evidence of the hypothesis.

Hoering has explored the possible mechanisms of these geochemical transformations. From synthetic organic chemistry, it is known that acid-catalyzed rearrangements involve carbonium ions—highly active ions which tend to undergo rearrangements from 2-methyl to 3-methyl isomer form, for example. (Carbonium ions are organic molecules carrying a positive charge often caused by the abstraction of an H^- hydride ion from the branching point in strongly acid systems.) Hoering heated Green River Shale in the presence of montmorillonite clay, adding as a "molecular probe" a small amount of 2-methyl octadecane. If hydride abstraction had taken place, an excess of 3-, 4-, and 5-methyl isomers would have formed from the molecular probe. But such compounds were not observed (see Fig. 30). Evidently, as had been previously suspected, montmorillonite is not sufficiently acidic to catalyze isomerization by this route.

Another, more speculative, mechanism involves the formation of carbonium ions by the reaction of H^+ ions from clay with the carbon-to-carbon double bonds in olefins—unsaturated hydrocarbons intermediate in the thermal cracking of kerogen to small molecules (see Fig. 31). Hoering hopes to conduct experiments using branched, unsaturated hydrocarbons as molecular probes.

The process shown in the drawing is a greatly simplified form of what may occur. Olefins under attack by hydrogen ions are known to react by several pathways to yield a multitude of products. Such complexity in geological matrices has hindered understanding of the natural transformation of natural organic matter. But the situation is changing. Modern methods of instrumental analysis, such as gas chromatography and mass spectrometry, and computer-assisted data gathering and management, make it possible to study such systems in detail. Hoering's experiments show how chemical processes occurring in a shale can be studied in the context of modern organic chemistry.

Professional Activities

Like scientists everywhere, Carnegie staff members continued to participate in seminars and symposia, deliver invited lectures, and attend conferences in special subject areas. Many served as chairpersons for panels or conferences, or as organizers for meetings. This year, for example, Allan Spradling of the Department of Embryology served as co-chair of the Gordon Conference on Developmental Biology. Geophysical Laboratory staff member Bjørn Mysen organized the International Conference and Field Study of Physicochemical Principles of Magmatic Processes, held in honor of Geophysical Laboratory director Hatten S. Yoder, Jr., in Hawaii during June. John Graham of DTM chaired the scientific organizing committee of the International Astronomical Union Symposium on Instrumentation and Research Programs for Small Telescopes.

Several of the Institution's postdoctoral fellows, too, served in leadership capacities. (Indeed, individuals tend to be selected for fellowships by the departments partly for their independence and leadership potential.) This year, postdoctoral fellow Julie Morris of DTM co-chaired a session on arc petrology at the spring meeting of the American Geophysical Union. During December 1985, Department of Embryology postdoctoral fellow Lynn Cooley and graduate student Suki Parks organized the Department's ninth annual minisymposium, "Parasitology: Molecular Approaches to a Global Problem."

Carnegie scientists also served as officers for scientific societies, editors of scientific journals, and members of advisory or awards committees. Some participated in educational or public service–oriented ventures. Many, for instance, have joint appointments as professors in local universities; this has been true for many years at the Department of Plant Biology, located on the campus of Stanford University, and at the Department of Embryology, near the Johns Hopkins University. This year, Paul Silver of DTM became a research associate professor at Hopkins, in the Department of Earth and Planetary Sciences.

Still other Carnegie scientists participated in educational ventures apart from the university campus. Vice president Margaret MacVicar was named a member of the National Science Foundation's Advisory Committee to the Directorate for Science and Education. She also is co-chair of Project 2016 of the American Association for the Advancement of Science, which is responsible for revising the math and science curriculum for grades kindergarten through 12. Vera Rubin of DTM was a lecturer at the Vatican Observatory summer

school in 1986, lecturing daily for over a month. She reports that of her 25 beginning graduate students, 17 came from nonindustrialized countries. Rubin, Julie Morris, and Deidre Hunter gave talks at local high schools during National Science Week. Sondra Lazarowitz of Embryology presented a class and lab to tenth grade students at the Maryland Science Center.

In an educational activity more oriented to the layperson, DTM's Alan Boss gave an interview about the Moon's origin on the Canadian Broadcasting Company's "Quirks and Quarks" radio science series. Paul Schechter of the Observatories and postdoctoral fellow Kirk Borne of DTM gave several interviews about galaxy rotational properties on Carnegie's own radio series—Perspectives in Science. Alan Dressler of the Observatories and Schechter were interviewed on National Public Radio's All Things Considered program, and Carnegie president James Ebert discussed "One Hundred Years of American Biology" in a broadcast recorded at the National Humanities Center, North Carolina, for the series Soundings.

Some scientists performed service activities in areas slightly removed from their major fields of study. Geophysical Laboratory staff member Douglas Rumble, for example, served this year as an assistant program director at the National Science Foundation's Earth Science Division. Joseph Gall of Embryology was a member of the Board of Science Counselors of the National Institute of Child Health and Human Development of NIH. Plant Biology's Joseph Berry continued his participation in studies on the long-term consequences of nuclear war. This year, he contributed to a report of the Greater London Area War Risk Study Commission.

Seminars at the Departments. During the report year, each Department, as usual, hosted weekly seminars, attended by members of the local science communities. As well, many of the individual laboratories continued to hold regular meetings among themselves to discuss research progress, problems, and results. At DTM, this practice extended to an interdisciplinary group of astronomers and earth scientists called the Solar System Cosmogony Group. This group, which includes George Wetherill, John Graham, Alan Boss, Richard Carlson, and Steven Shirey, has been supported for the past four years by the Innovative Research Program of the National Aeronautics and Space Administration.

Special Events. In August 1985, celebrating the 150th anniversary of Andrew Carnegie's birth, a delegation from the Institution, including the president, vice president, all five directors, and several trustees, traveled to Dunfermline, Scotland, Mr. Carnegie's birthplace. There, with representatives from other Carnegie organizations, they participated in a one-day symposium entitled

"The Role of Philanthropy in a Changing World." On the following day, Plant Biology director Winslow Briggs, Embryology director Donald Brown, and John Gurdon, a U.K. scientist with close ties to the Department of Embryology, were members of a panel devoted to Carnegie Institution science.

The first Joint Visiting Committee of the Department of Terrestrial Magnetism and the Geophysical Laboratory met at the Washington campuses on January 20–21. Members of the Committee were trustee Edward David, Jr., chair, Alar Toomre (MIT), Charles Prewitt (then of SUNY at Stony Brook), David Stevenson (Caltech), Thomas Ahrens (Caltech), Marco Einaudi (Stanford University), David Walker (Lamont-Doherty Geological Observatory, Columbia University), W. Gary Ernst (UCLA), and Stanley Hart (MIT). The two-day program was highlighted by presentations of work-in-progress by several scientists from each department.

The Visiting Committee to the Department of Plant Biology met at the Department on March 6–7. Its members included Antonia Ax:son Johnson, chair, trustees William R. Hewlett, John Diebold, and William F. Kieschnick, and Martyn Caldwell (Utah State University), Joseph Key (University of Georgia), David Krogmann (Purdue University), Peter Quail (University of Wisconsin, Madison), and Joseph Varner (Washington University).

His Excellency Hernán Felipe Errázuriz, the Ambassador of Chile, left, talks with George Preston, center, and Ray Weymann. Preston delivered the 1986 Carnegie Lecture, "An Eight-Meter Telescope for the 21st Century."

Losses, Gains, Honors....

We report with sadness the deaths of two former trustees. Robert A. Lovett served the Institution from 1948 to 1971. Throughout his career as a banker and public servant, Lovett played a key role in the development of the nation's post–World War II defense policy. He worked closely with Secretary of State General George C. Marshall in persuading Congress to provide aid for a devastated Europe. When Marshall became Secretary of Defense, Lovett became his Deputy Secretary. From 1951 to 1953, Lovett served as Secretary of Defense, after which he returned full-time to his private banking practice in New York City. He died on May 7, 1986, at the age of 91.

J. Paul Austin was a Carnegie trustee from 1976 to 1978. During this time, he was Chairman of the Board of the Coca-Cola Company. In 1981, he retired from the soft-drink company, to which he had devoted most of his career. He died on December 26, 1985, at the age of 70.

Two retired staff members of the Institution's former Department of Archaeology died this year. Tatiana Proskouriakoff, an expert on Mayan hieroglyphs, served the Institution first as a draftsperson (1939–1943), then as a staff member (1943–1959). When the Department closed, she joined the staff of Harvard's Peabody Museum, where she continued to study Mayan glyphs. She died in Cambridge, Massachusetts, on August 30, 1985. She was 76.

A. Ledyard Smith was a staff member of the Department of Archaeology from 1932 until 1948, at which time he joined the staff of the Peabody Museum. He died last spring at the age of 85.

Paul Scherer and Margaret Hale Scherer both died this year. Paul Scherer was executive officer of the Carnegie Institution under two presidents, Vannevar Bush and Caryl Haskins (1947–1961). He had earlier worked with Bush in the Office of Scientific Research and Development, which he joined in 1943 as chief of the Engineering and Transition Office. Paul and Margaret, George Ellery Hale's daughter, had been married since 1918. Margaret died on May 5, 1986, at the age of 89; Paul died on July 17. He was 88.

Stepping down from his post as Chairman of the Board in May 1986 was William R. Hewlett, who had served as a Carnegie trustee since 1971 and Chairman since 1980. Hewlett remains on the Board as trustee and as a member of the Executive Committee.

Retiring this year was Geophysical Laboratory director Hatten S. Yoder, Jr. Yoder joined the Laboratory in 1948 as a postdoctoral

Former executive officer Paul Scherer and his wife, Margaret, daughter of George Ellery Hale, died this year within four months of one another.

fellow after receiving his Ph.D. from the Massachusetts Institute of Technology. He became a staff member nine months later. In his early years at the Laboratory, Yoder developed a pressure-temperature apparatus that was able to attain experimental conditions comparable to those at the base of the continental crust. He became an expert on basaltic magma—its origin, requirements for melting, and mechanisms of accumulation. After becoming director in 1971, Yoder continued to do research. He has received many honors throughout his career, including election to the National Academy of Sciences, and the Academy's 1972 Arthur L. Day Prize. He was recognized most recently at the International Conference and Field Study of Physicochemical Principles of Magmatic Processes, held in his honor in Hawaii during June 1986.

Felix Chayes of the Geophysical Laboratory and Halton C. Arp of the Mount Wilson and Las Campanas Observatories retired this year. Chayes joined the Laboratory staff in 1947, after receiving his Ph.D. in petrology from Columbia University. Chayes has been particularly interested in the use of statistics in petrology, and has devoted many years toward systematizing the electronic storage, use, and retrieval of petrological data.

Halton Arp had been a staff member at the Observatories since 1957. He received his Ph.D. in 1953 from the California Institute of Technology, and was a fellow at Mount Wilson from 1953 until 1955. An astronomer of international reputation, Arp has received several awards, among them the 1960 Helen B. Warner Prize of

the American Astronomical Society and the 1984 Humboldt Prize, awarded for research at the Max-Planck-Institute for Physics and Astrophysics in Munich.

Others retiring this year were Richard D. Grill, Department of Embryology photographer since 1949, Charlie Batten, shop foreman and instrument maker at the Geophysical Laboratory since 1962, and Observatories driver William D. Qualls, who has been with Carnegie since 1978.

Gains

Richard E. Heckert, newly appointed chairman of E. I. du Pont de Nemours & Co., was elected Chairman of the Board of Trustees of the Carnegie Institution (for a three-year term) at the 89th annual meeting of the Board, held on May 9. Heckert has been a Carnegie trustee since 1980 and a member of its Executive Committee since 1983.

Elected as trustee, also for a three-year term, was Thomas N. Urban, president and chairman of Pioneer Hi-Bred International and an active public figure in Des Moines, Iowa. (He was Mayor of Des Moines from 1968 until 1971). Urban joined Pioneer Hi-Bred in 1960 and, except for a two-year leave in the early 1970's, has served the company ever since. He holds undergraduate and MBA degrees from Harvard University.

Two new departmental directors were appointed this year, effective July 1, 1986. Ray J. Weymann became director of the Mount Wilson and Las Campanas Observatories, replacing George Preston, who remains at the Observatories as staff member. Weymann was most recently professor of astronomy at the University of Arizona's Steward Observatory. He received his Ph.D. from Princeton in 1959, and worked at Caltech and the University of Arizona. He became a professor at the University in 1967. He served as director of the Steward Observatory and as head of the University's astronomy department from 1970 to 1975. A member of the National Academy of Sciences, Weymann is known for his contributions to stellar spectroscopy and study of Seyfert galaxies, and, more recently, for studies on quasars and gravitational lenses.

At the Geophysical Laboratory, Charles T. Prewitt succeeds Hatten S. Yoder, Jr., as director. Prewitt came to Carnegie from the State University of New York at Stony Brook, where he had served since 1969; he became professor of earth science and materials science there in 1975. A crystallographer and mineralogist by training, Prewitt received his S.B., S.M., and Ph.D. degrees from the Massachusetts Institute of Technology. His current studies involve development of structural models for minerals at high temperatures and pressures.

Honors

Donald D. Brown, director of the Department of Embryology, was a co-recipient of Columbia University's 1985 Louisa Gross Horwitz Prize. The Horwitz Prize is bestowed to a scientist or scientists who have made outstanding contributions to basic research in the fields of biology or biochemistry. Brown also delivered the 1985 DeWitt Stetten, Jr., Lecture of the National Institute of General Medical Sciences, NIH, and the 1985 Robert and Esther Stadtler Lecture, University of Texas System Cancer Center, Houston.

George W. Wetherill, director of the Department of Terrestrial Magnetism, received the Gerard P. Kuiper Prize from the Division for Planetary Sciences of the American Astronomical Society on November 4, 1986, in Paris. The Prize is awarded annually to a scientist whose achievements have "most advanced the understanding of planetary sciences."

Carnegie vice president Margaret L. A. MacVicar received a Charles A. Dana Commendation for Pioneering Achievement in Higher Education from the Charles A. Dana Foundation on November 6, 1986. She received the 1986 Educator of the Year, Valerie A. Knapp Award from the College Club of Boston in February 1986. She spoke at the commencement exercises of Harvey Mudd College on May 18, 1986.

Olle Björkman, staff member at the Department of Plant Biology, received the Stephen Hales award from the American Society of Plant Physiologists for his outstanding contributions in the area of physiological ecology. He was also elected a Foreign Associate of the Australian Academy of Sciences, and a Fellow of the American Association for the Advancement of Science.

Geophysical Laboratory staff member Robert M. Hazen received the Ipatieff Prize of the American Chemical Society on April 14, 1985, for "his outstanding contributions relating crystal structures determined at high pressures and high temperatures to thermodynamic properties, and the generation of theory important to the fundamental characterization of minerals."

Embryology staff associate Martin Snider was selected one of twenty 1986 Pew Scholars in the Biomedical Sciences by the Pew Memorial Trust of Philadelphia.

Roy J. Britten, Staff Member in Special Subject Area, was elected a Fellow of the American Academy of Arts and Sciences in October 1986.

Emeritus staff member Olin C. Wilson of the Observatories received a Lifetime Achievement Award for his contributions to astronomy at the fourth Cambridge Workship on Cool Stars, Stellar Systems, and the Sun, held in October 1985 at Santa Fe.

Barbara McClintock, Distinguished Service Member of the Institution, was inducted into the Women's Hall of Fame in Seneca, New York, on March 8, 1986.

Allan Sandage of the Observatories received an honorary D.Sc. from Graceland College, Iowa.

DTM staff member Alan T. Linde received a Japan Society for the Promotion of Science Fellowship.

Plant Biology postdoctoral fellows Neal Woodbury and Lamont Anderson and former predoctoral fellow David Stern received 1985 National Science Foundation Fellowships in Plant Biology.

Former Embryology staff member Gerald Rubin (1980–1983) received the 1986 Genetics Society of America Medal. Rubin is now at the University of California, Berkeley.

Former Embryology postdoctoral fellow Robert Roeder (1969–1972), now at Rockefeller University, received the National Academy of Sciences' U.S. Steel Foundation Award in Molecular Biology.

Edwin Roedder, former fellow at the Geophysical Laboratory (1947–1948), received the Deutsche Mineralogische Gesellschaft 1985 Abraham Gottlob Werner Medal. Former Geophysical associate Alvin Van Valkenburg (1975–1980) received the 1985 John Price Wetherill Medal from the Franklin Institute for his role in the development of the diamond-cell pressure device. And former senior research associate Friedrich A. Seifert was elected director of the Bavarian Research Institute for Experimental Geochemistry and Geophysics, University of Bayreuth, Federal Republic of Germany.

James Van Allen, former DTM fellow (1939–1941), received the first Philip Hauge Abelson Prize of the American Association for the Advancement of Science in May 1986 for his discovery of the Van Allen Radiation Belts.

In May 1986, trustee Charles H. Townes was co-recipient of the L. W. Frohlich Award, which is administered by the New York Academy of Sciences and is jointly sponsored by the Academy, Columbia University, and New York University.

Trustee Sandra M. Faber received the Dannie Heineman Prize in January 1986 at the Houston meeting of the American Astronomical Society.

In honor of his service as chairman of the Aerospace Corporation's Board of Trustees, Carnegie trustee Robert C. Seamans, Jr., received the Air Force Exceptional Service Award. He also received the Durand Lectureship for Public Service from the American Institute of Aeronautics and Astronautics in April 1986.

Edward E. David, Jr., received an Honorary Fellow Award from the American Institute of Chemists, Inc., in November 1985. In December, he received an Honorary Doctor of Science degree from the University of Pennsylvania.

Chairman Richard E. Heckert was the first recipient of the George P. Baker Leadership Award, initiated by the Joint Council on Economic Education and bestowed in December 1985.

William T. Golden received the annual Owl Award from Columbia University's School of General Studies on May 7, 1986. He also received an honorary Doctor of Laws degree from Columbia.

Trustee Emeritus Frank Stanton received an honorary Doctor of Laws degree from Harvard University in 1985.

George Wetherill's poem about Comet Halley, a part of which is printed on page 3, is printed here in full.

Among the eucalyptus trees,
Green leaves dancing in the autumn wind,
The cold pale watcher of mankind
Treads his ancient trail again.

Pass swiftly by the angry bull,
The starry fish and water jar,
Defy the Sun's consuming flame,
The archer's bow,
The scorpion's sting,
The centaur's wrath,
The deadly coil of the hydra—
But then be gone.
Ask not for Harold of Hastings,
You know he is not here;
Nor Attila, vanquished at Chalons,
Edmund, master of Isaac's rules,
Nor Giotto, and the Zealots of Jerusalem.

You must have seen
The ships that rose to greet you.
Next time there will be more.
They'll even mount your haggard head
And ride you into Neptune's night!
Yes, we still are bold.
Though once more we now learn
The message that you bear,
Resonate to your grim tattoo,
The gravest rhythm of our race,
Yet wait with hope your sure return.

George Wetherill
La Serena, April 1986

Bibliography of Published Work and Work Accepted for Publication

DEPARTMENT OF EMBRYOLOGY

Reprints of the publications listed below can be obtained at no charge from the Department of Embryology, 115 West University Parkway, Baltimore, MD 21210.

Donald D. Brown

____ Brown, D. D., Corporate and foundation support on nontargeted biological research in nonprofit institutions, *Cell 44*, 373–374, 1986.

____ Brown, D. D., How embryologists became developmental biologists and other matters, *Perspectives in Biology and Medicine 29*, No. 3, Part 2, S149–S153, 1986.

____ Brown, D. D., and M. S. Schlissel, A positive transcription factor controls the differential expression of two 5S RNA genes, *Cell 42*, 759–767, 1985.

____ Brown, D. D., and M. S. Schlissel, The molecular basis of differential gene expression of two 5S RNA genes, *Cold Spring Harbor Symp. Quant. Biol. 50*, 549–553, 1985.

____ Taylor, W., I. J. Jackson, N. Siegel, A. Kumar, and D. D. Brown, The developmental expression of the gene for TFIIIA in Xenopus laevis, *Nucl. Acids Res. 14*, 6185–6195, 1986.

____ Wolffe, A. P., E. Jordan, and D. D. Brown, A bacteriophage RNA polymerase transcribes through a Xenopus 5S RNA gene transcription complex without disrupting it, *Cell 44*, 381–389, 1986.

____ Wolffe, A. P., and D. D. Brown, DNA amplification in vitro erases a Xenopus 5S RNA gene transcription complex, *Cell 47*, 217–227, 1986.

____ Wolffe, A. P., and D. D. Brown, Transcription and replication through a 5S RNA gene transcription complex, in *RNA Polymerase and the Regulation of Transcription: Proceedings of the Sixteenth Steenbock Symposium*, Elsevier Science Press, New York, in press.

Nina V. Fedoroff

____ Fedoroff, N. V., Biochemical and molecular techniques in maize research, *Genet. Eng. 7*, 115–133, 1985.

____ Fedoroff, N. V., Maize transposable controlling elements, in *Proceedings of the 16th FEBS Congress, Part C*, pp. 91–98, V.N.U. Science Press, 1985.

____ Fedoroff, N. V., Moving genes in maize, in *Proceedings of the ASM Symposium on Engineered Organisms in the Environment: Scientific Issues*, H. O. Halvorson, D. Banner, and M. Rogul, eds., pp. 70–75, American Society for Microbiology, Washington, D.C., 1985.

____ Fedoroff, N., Activation of *Spm* and *Modifier* elements, *Maize Genet. Coop. Newsletter 60*, 18–20, 1986.

____ Fedoroff, N., The recombinant DNA controversy: a contemporary cautionary tale, *Syracuse Scholar 7*, 19–33, 1986.

____ Banks, J., J. Kingsbury, V. Raboy, J. W. Schiefelbein, O. Nelson, and N. Fedoroff, The *Ac* and *Spm* controlling element families in maize, *Cold Spring Harbor Symp. Quant. Biol. 50*, 301–311, 1985.

____ Schell, J., H. Klaulen, F. Kreuzaler, P. Eckes, S. Rosahl., L. Willmitzer, A. Spena, B. Baker, L. Herrera-Estrella, and N. Fedoroff, Transfer and regulation of expression of chimeric genes in plants, *Cold Spring Harbor Symp. Quant. Biol. 50*, 421–431, 1985.

____ Schiefelbein, J. W., V. Raboy, N. V. Fedoroff, and O. E. Nelson, Jr., Deletions within a defective *Suppressor-mutator* element in maize affect the frequency and developmental timing of its excision from the *bronze* locus, *Proc. Natl. Acad. Sci. USA 82*, 4783–4787, 1985.

Joseph G. Gall

____ Gall, J. G., ed., *Gametogenesis and the Early Embryo: 44th Symposium of the Society for Developmental Biology*, Alan R. Liss, Inc., New York, 1986.

____ Berg, C. A., and J. G. Gall, Microinjected *Tetrahymena* rDNA ends are not recognized as telomeres in Xenopus eggs, *J. Cell Biol. 103*, 691–698, 1986.

____ Epstein, L. M., K. A. Mahon, and J. G. Gall, Transcription of a satellite DNA in the newt, *J. Cell Biol. 103*, 1137–1144, 1986.

____ Warrior, R., and J. G. Gall, The mitochondrial DNA of *Hydra attenuta* and *Hydra littoralis* consists of two linear molecules, *Arch. Sci. (Geneve) 38*, 439–445, 1985.

____ Wu, Z., C. Murphy, and J. G. Gall, A transcribed satellite DNA from the bullfrog *Rana catesbeiana*, *Chromosoma 93*, 291–297, 1986.

Sondra G. Lazarowitz

____ Lazarowitz, S. G., The molecular characterization of Squash Leaf Curl and Maize Streak

Viruses (Abst.), in *Proceedings of the EMBO Workshop on DNA Plant Infectious Agents*, August, 1985.
—— Lazarowitz, S. G., Molecular characterization of the genome of squash leaf curl virus: identification of two closely related bipartite geminiviruses with different host ranges, *EMBO J.*, in press.
—— Lazarowitz, S. G., The molecular characterization of geminiviruses, *Plant Mol. Biol. Rep.*, in press.

Steven L. McKnight

—— Graves, B. J., P. F. Johnson, and S. L. McKnight, Homologous recognition of a promotor domain common to the MSV LTR and the HSV tk gene, *Cell 44*, 565–576, 1986.
—— McKnight, S. L., and R. Tjian, Transcription selectivity of viral genes in mammalian cells, *Cell 46*, 795–805, 1986.
—— Coen, D. M., S. P. Weinheimer, and S. L. McKnight, A genetic approach to promoter recognition during trans induction of viral gene expression, *Science 234*, 53–59, 1986.

Richard E. Pagano

—— Pagano, R. E., and R. G. Sleight, Defining lipid transport pathways in animal cells, *Science 229*, 1051–1057, 1985.
—— Pagano, R. E., and R. G. Sleight, Emerging problems in the cell biology of lipids, *Trends Biochem. Sci. 10*, 421–425, 1985.
—— Uster, P. S., and R. E. Pagano, Synthesis and properties of fluorescent analogs of cytidine diphosphate-diacylglycerol and phosphatidylinositol, in *Enzymes of Lipid Metabolism, Vol. II*, L. Freysz, R. Massarelli, H. Dreyfus, and S. Gatt, eds., Plenum Pub., New York, in press.
—— Uster, P. S., and R. E. Pagano, Resonance energy transfer microscopy: observations of membrane-bound fluorescent probes in model membranes and in living cells, *J. Cell Biol. 103*, 1221–1234, 1986.

David C. Schwartz

—— Schwartz, D. C., Pulsed electrophoresis, in *New Directions in Electrophoretic Methods: A.C.S. Symposium Series No. 335*, M. Phillips and J. Jorgenson, eds., American Chemical Society, Washington, D.C., in press.

Martin D. Snider

—— Snider, M. D., and O. C. Rogers, Membrane traffic in animal cells. Cellular glycoproteins return to the site of Golgi mannosidase I, *J. Cell Biol. 103*, 265–275, 1986.
—— Brands, R., M. D. Snider, Y. Hino, S. S. Park, H. V. Gelboin, and J. E. Rothman, The retention of membrane proteins by the endoplasmic reticulum, *J. Cell Biol. 101*, 1724–1732, 1985.

Allan Spradling

—— Spradling, A., P-element mediated transformation, in *Drosophila, a Practical Approach*, D. B. Roberts, ed., pp. 175–197, IRL Press, Oxford, 1986.
—— Kalfayan, L., J. Levine, T. Orr-Weaver, S. Parks, B. Wakimoto, D. deCicco, and A. Spradling, Localization of sequences regulating Drosophila chorion gene amplification and expression, *Cold Spring Harbor Symp. Quant. Biol. 50*, 527–535, 1985.
—— Levine, J., and A. Spradling, DNA sequence of a 3.8-kb region controlling Drosophila chorion gene amplification, *Chromosoma 92*, 136–142, 1985.
—— Orr-Weaver, T., and A. Spradling, An upstream region required for s18 chorion gene transcription is also essential for amplification, *Mol. Cell Biol.*, in press.
—— Parks, S., and A. Spradling, Replication and expression of a X-linked cluster of Drosophila chorion genes, *Devel. Biol. 117*, 294–305, 1986.
—— Wakimoto, B., L. Kalfayan, and A. Spradling, Developmentally regulated expression of Drosophila chorion genes introduced at diverse chromosomal positions, *J. Mol. Biol. 187*, 33–45, 1986.

Samuel Ward

—— Ward, S., The asymmetric localization of gene products during the development of *Caenorhabditis elegans* spermatozoa, in *Gametogenesis and the Early Embryo: 44th Symposium of the Society for Developmental Biology*, J. G. Gall, ed., pp. 55–76, Alan R. Liss., Inc., New York, 1986.
—— Ward, S., T. M. Roberts, S. Strome, F. M. Pavalko, and E. Hogan, Monoclonal antibodies that recognize a polypeptide antigenic determinant shared by multiple *Caenorhabditis elegans* sperm-specific proteins, *J. Cell Biol. 102*, 1778–1786, 1986.
—— Bennett, K. L., and S. Ward, Chromatin diminution in *Ascaris lumbricoides*, in *Molecular Strategies of Parasite Invasion: Proceedings of the MacArthur Foundation–UCLA Symposium*, N. Agabian *et al.*, eds., Alan R. Liss, Inc., New York, in press.
—— Roberts, T. M., F. M. Pavalko, and S. Ward, Membrane and cytoplasmic proteins are transported in the same organelle complex during nematode spermatogenesis, *J. Cell Biol. 102*, 1787–1796, 1986.
—— Bennett, K. L., and S. Ward, Neither a germline specific nor somatic gene are lost or rearranged during chromatin diminution in *Ascaris lumbricoides* var. *suum.*, *Devel. Biol.*, in press.

DEPARTMENT OF PLANT BIOLOGY

Reprints of the numbered publications listed below can be obtained at no charge from the Department of Plant Biology, 290 Panama St., Stanford, CA 94305. Please give reprint number(s) when ordering.

Lamont Anderson

964 Anderson, L., and A. R. Grossman, Phycocyanin genes in the cyanobacterium Synechocystis 6701 and a potential gene rearrangement in a pigment variant, in *Proceedings of the VII International Conference on Photosynthesis*, Brown University, Providence, Rhode Island, in press.

J. Timothy Ball

904 Ball, J. T., On calculations related to gas exchange, in *Stomatal Function*, E. Zeiger, I. R. Cowan, G. D. Farquhar, eds., Stanford University Press, in press.

Tobias I. Baskin

852 Baskin, T. I., M. Iino, P. B. Green, and W. R. Briggs, High-resolution measurement of growth during first positive phototropism in maize, *Plant Cell Environ. 8*, 595–603, 1985.

895 Baskin, T. I., W. R. Briggs, and M. Iino, Can lateral redistribution of auxin account for phototropism in maize coleoptiles? *Plant Physiol. 81*, 306–309, 1986.

921 Baskin, T. I., Redistribution of growth occurs during first-positive phototropism of the pea epicotyl, *Planta*, in press.

Joseph A. Berry

871 Greer, D., J. A. Berry, and O. Björkman, Photoinhibition of photosynthesis in intact bean leaves: role of light and temperature and requirement for chloroplast-protein synthesis during recovery, *Planta 168*, 253–260, 1986.

892 Lucas, W. J., and J. A. Berry, eds., *Inorganic Carbon Uptake by Aquatic Photosynthetic Organism*, Proceedings of the International Workshops on Bicarbonate Use in Photosynthesis, Commemorating 75th Anniversary of University of California at Davis, American Society of Plant Physiologists, 1985.

893 Mott, K. A., and J. A Berry, Effects of pH on activity and activation of ribulose 1, 5-bisphosphate carboxylase at air level of CO_2, *Plant Physiol. 82*, 77, 1986.

907 Seemann, J. R., J. A. Berry, S. M. Freas, and M. A. Krump, Regulation of ribulose bisphosphate carboxylase activity *in vivo* by a light-modulated inhibitor of catalysis, *Proc. Natl. Acad. Sci. USA 82*, 8024–8028, 1985.

919 Sharkey, T. D., J. R. Seemann, and J. A. Berry, Regulation of ribulose-1, 5,-bisphosphate carboxylase activity in response to changing partial pressure CO_2 and light in *Phaseolus vulgaris, Plant Physiol. 81*, 788–791, 1986.

922 Seemann, J. R., W. J. S. Downton, and J. A. Berry, Temperature and leaf osmotic potential as factors in the acclimation of photosynthesis to high temperature in desert plants, *Plant Physiol. 80*, 926–930, 1986.

941 Mott, K. A., R. G. Jensen, and J. A. Berry, Limitation of photosynthesis by RUBP regeneration, in *Biological Control of Photosynthesis*, R. Marcelie, H. Clijsters, and M. Poucke, eds., pp. 33–43, Martinus Nijhoff Publ., Dordrecht, The Netherlands, 1986.

948 Lucas, W. J., and J. A. Berry, Inorganic carbon transport in aquatic photosynthetic organisms, *Physiol. Plant. (What's New in Plant Physiology) 65*, 539–543, Copenhagen, 1985.

950 Evans, J. R., T. D. Sharkey, J. A. Berry, and G. D. Farquhar, Carbon isotope discrimination measured concurrently with gas exchange to investigate CO_2 diffusion in leaves of higher plants, *Aust. J. Plant Physiol. 13*, 281–292, 1986.

952 Berry, J. A., G. H. Lorimer, J. Pierce, J. R. Seemann, J. Meek, and S. Freas, Isolation, identification, and synthesis of carboxyarabinitol-1-phosphate, a diurnal regulation of ribulose bisphosphate carboxylase activity, *Proc. Natl. Acad. Sci. USA*, in press.

Grazyna Bialek-Bylka

913 Bialek-Bylka, G., and J. S. Brown, Spectroscopy of native chlorophyll-protein complexes embedded in polyvinyl alcohol films, *Photobiochem. Photobiophys.*, in press.

Olle Björkman

871 Greer, D., J. A. Berry, and O. Björkman, Photoinhibition of photosynthesis in intact bean leaves: role of light and temperature and requirement for chloroplast-protein synthesis during recovery, *Planta 168*, 253–260, 1986.

923 Björkman, O., and B. Demmig, Photon yield of O_2 evolution and chlorophyll fluorescence characteristics at 77K among vascular plants of diverse origins, *Planta*, in press.

926 Demmig, B., and O. Björkman, Susceptibility to photoinhibition in leaves of higher plants as influenced by growth light regime, *Planta*, in press.

947 Pearcy, R. W., O. Björkman, M. M. Caldwell, J. E. Keeley, R. L. Monson, and B. R. Strain, Carbon gain by plants in natural environments, *BioScience*, in press.

Salil Bose

909 Fork, D. C., S. Bose, and S. K. Herbert, Radiationless transition as a possible mechanism of protection against photoinhibition in higher plants and a red alga, *Photosyn. Res.*, in press.

Winslow R. Briggs

852 Baskin, T. I., M. Iino, P. B. Green, and W. R. Briggs, High-resolution measurement of growth during first positive phototropism in maize, *Plant Cell Environ. 8*, 595–603, 1985.

866A Kaufman, L. S., J. C. Watson, W. R. Briggs, and W. F. Thompson, Photoregulation of nuclear-encoded transcripts: blue-light regulation of specific transcript abundance, in *Molecular Biology of the Photosynthetic Apparatus*, K. Steinbeck *et al.*, eds., pp. 367–372, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York, 1985.

878 Shinkle, J. R., and W. R. Briggs, Physiological mechanism of the auxin-induced increase in light sensitivity of phytochrome-mediated growth responses in *Avena* coleoptile sections, *Plant Physiol. 79*, 349–356, 1985.

879 Koller, D., I. Levitan, and W. R. Briggs, The vectorial photo-excitation in solar-tracking leaves of *Lavatera cretica* (Malvaceae), *Photochem. Photobiol. 42*, 717–723, 1985.

880 Koller, D., I. Levitan, and W. R. Briggs, Components of vectorial photo-excitation in solar-tracking leaves of *Lavatera cretica* (Malvaceae), *Physiol. Veget. 23*, 913–920, 1985.

896 Shinkle, J. R., and W. R. Briggs, Optimization of red light–induced elongation in *Avena* coleoptile sections and properties of the phytochrome-mediated growth response, *Plant Cell Environ. 9*, 165–173, 1986.

895 Baskin, T. I., W. R. Briggs, and M. Iino, Can lateral redistribution of auxin account for phototropism in maize coleoptiles? *Plant Physiol. 81*, 306–309, 1986.

901 Kaufman, L. S., L. Roberts, W. R. Briggs, and W. F. Thompson, Phytochrome control of specific mRNA levels in developing pea buds: kinetics of accumulation, reciprocity and escape kinetics of the low fluence response, *Plant Physiol. 81*, 1033–1038, 1986.

910 Shäfer, E., and W. R. Briggs, Photomorphogenesis from signal perception to gene expression, *Photobiochem. Photobiophys.*, in press.

934 Briggs, W. R., E. Mösinger, A. Batschauer, K. Apel, and E. Schäfer, Molecular events in photoregulated greening in barley leaves, in *Molecular Biology of Plant Growth Control*, J. E. Fox and M. Jacobs, eds., UCLA Symposia on Molecular and Cellular Biology, New Series, Vol. 44, Alan R. Liss, Inc., New York, in press.

Jeanette S. Brown

856 Acker, S., J. S. Brown, and J. Duranton, Absorption and circular dichroism spectra of chlorophyll and β carotene in photosynthetic system I, in *Photosynthetica*, in press.

876 Brown, J. S., Chlorophyll absorption and fluorescence in photosynthetic membranes, in *Model Building in Plant Physiology/Biochemistry*, CRC Press, Boca Raton, Florida, in press.

913 Bialek-Bylka, G., and J. S. Brown, Spectroscopy of native chlorophyll-protein complexes embedded in polyvinyl alcohol films, *Photobiochem. Photobiophys.*, in press.

917 Duranton, J., and J. S. Brown, Evidence for a light-harvesting chlorophyll a–protein complex in a chlorophyll b–less barley mutant, *Photosyn. Res.*, in press.

933 Schoch, S., and J. S. Brown, The action of chlorophyllase on chlorophyll-protein complexes, *J. Plant Physiol.*, in press.

Robin L. Chazdon

911 Chazdon, R. L., and R. W. Pearcy, Photosynthetic responses to light variation in rainforest species. I. Induction under constant and fluctuating light conditions, *Oecologia 69* (Berlin), 517–523, 1986.

912 Chazdon, R. L., and R. W. Pearcy, Photosynthetic responses to light variation in rainforest species. II. Carbon gain and photosynthetic efficiency during lightflecks, *Oecologia 69* (Berlin), 524–531, 1986.

Pamela B. Conley

905 Conley P., P. Lemaux, T. L. Lomax, and A. R. Grossman, Genes encoding major light-harvesting polypeptides are clustered on the genome of the cyanobacteria *Fremyella diplosiphon*, *Proc. Natl. Acad. Sci. USA 83*, 3924-3928, 1986.

951 Grossman, A. R., P. G. Lemaux, and P. B. Conley, Regulated synthesis of phycobilisome components, *Photochem. Photobiol.*, in press.

Barbara Demmig

923 Björkman, O., and B. Demmig, Photon yield of O_2 evolution and chlorophyll fluorescence characteristics at 77K among vascular plants of diverse origins, *Planta*, in press.

926 Demmig, B., and O. Björkman, Susceptibility to photoinhibition in leaves of higher plants as influenced by growth light regime, *Planta*, in press.

Michael S. Dobres

928 Dobres, M. S., R. C. Elliott, J. C. Watson, and W. F. Thompson, A phytochrome regulated pea transcript encodes ferredoxin, *Plant Mol. Biol.*, in press.

Robert C. Elliott

928 Dobres, M. S., R. C. Elliott, J. C. Watson, and W. F. Thompson, A phytochrome regu-

lated pea transcript encodes ferredoxin, *Plant Mol. Biol.*, in press.

Christopher B. Field

898 Field, C. B., Leaf-age effects on stomatal conductance, in *Stomatal Fixation*, E. Zieger, G. D. Farquhar, and I. R. Cowan, eds., Stanford University Press, in press.

915 Chapin, T. S., A. Bloom, C. B. Field, and R. H. Waring, Plant responses to multiple environmental factors, *BioScience*, in press.

930 Field, C. B., and H. A. Mooney, Measuring photosynthesis under field conditions–Past and present approaches, in *Scientific Instruments in Physiological Plant Ecology*, P. J. Kramer, B. R. Strain, S. Funada, Y. Hashimoto, eds., Academic Press, New York, in press.

931 Ehleringer, J. R., Z.-F. Lin, C. B. Field, and C.-Y. Kuo, Leaf carbon isotope ratios of plants from a sub-tropical monsoonal forest, *Tree Physiol.*, in press.

932 Ehleringer, J. R., Z.-F. Lin, C. B. Field, and C.-Y. Kuo, Leaf carbon isotope and mineral composition in subtropical plants along an irradiance cline, *Oecologia*, in press.

David C. Fork

855 Fork, D. C., and P. Mohanty, Blue-green algae (cyanobacteria), red algae and cryptomonads, in *Light Emission from Plants and Bacteria*, Govindjee, J. Amesz, and D. C. Fork, eds., Academic Press, New York, in press.

859 Smith, C. M., K. Satoh, and D. C. Fork, The effects of osmotic tissue dehydration and air drying on morphology and energy transfer in two species of *Porphyra*, *Plant Physiol. 80*, 843–847, 1986.

873 Williams, W. P., A. Sen, and D. C. Fork, Selective photobleaching of PS1-related chlorophylls in heat-stressed pea chloroplasts, *Photosyn. Res. 10*, 75–92, 1986.

877 Fork, D. C., P. Mohanty, and S. Hoshina, The detection of early events in heat disruption of thylakoid membranes by delayed light emission, *Physiol. Veget. 23*, 511–521, 1985.

885 Fork, D. C., and K. Satoh, The control by state transitions of the distribution of excitation energy in photosynthesis, *Annu. Rev. Plant Physiol. 37*, 335–361, 1986.

893A Fork, D. C., A. Sen, and W. P. Williams, The relationship between heat-stress and photobleaching in green and blue-green algae, *Photosyn. Res.*, in press.

909 Fork, D. C., S. Bose, and S. K. Herbert, Radiationless transition as a possible mechanism of protection against photoinhibition in higher plants and a red alga, *Photosyn. Res.*, in press.

943 Fork, D. C., Photosynthesis, in *The Science of Photobiology*, K. C. Smith, ed., Plenum-Rosetta, New York, in press.

944 Govindjee, J. Amesz, and D. C. Fork, eds., *Light Emission from Plants and Bacteria*, Academic Press, Orlando, Florida, in press.

Suzan M. Freas

907 Seemann, J. R., J. A. Berry, S. M. Freas, and M. A. Krump, Regulation of ribulose bisphosphate carboxylase activity *in vivo* by a light-modulated inhibitor of catalysis, *Proc. Natl. Acad. Sci. USA 82*, 8024–8028, 1985.

Arthur R. Grossman

868 Fawley, M., and A. R. Grossman, Polypeptides of a light-harvesting complex of the diatom *Phaeodactylum tricornutum* are synthesized in the cytoplasm of the cell as precursors, *Plant Physiol. 81*, 149–155, 1986.

905 Conley P., P. Lemaux, T. L. Lomax, and A. R. Grossman, Genes encoding major light-harvesting polypeptides are clustered on the genome of the cyanobacteria *Fremyella diplosiphon*, *Proc. Natl. Acad. Sci. USA 83*, 3924-3928, 1986.

940 Mullet, J. E., R. R. Klein, and A. R. Grossman, Optimization of protein synthesis in isolated higher plant chloroplasts (Identification of paused translation intermediates), *Eur. J. Biochem. 155*, 331–338, 1986.

951 Grossman, A. R., P. G. Lemaux, and P. B. Conley, Regulated synthesis of phycobilisome components, *Photochem. Photobiol.*, in press.

964 Anderson, L., and A. R. Grossman, Phycocyanin genes in the cyanobacterium Synechocystis 6701 and a potential gene rearrangement in a pigment variant, in *Proceedings of the VII International Conference on Photosynthesis*, Brown University, Providence, Rhode Island, in press.

Satoshi Hoshina

877 Fork, D. C., P. Mohanty, and S. Hoshina, The detection of early events in heat disruption of thylakoid membranes by delayed light emission, *Physiol. Veget. 23*, 511–521, 1985.

Moritoshi Iino

852 Baskin, T. I., M. Iino, P. B. Green, and W. R. Briggs, High-resolution measurement of growth during first positive phototropism in maize, *Plant Cell Environ. 8*, 595–603, 1985.

864 Iino, M., T. Ogawa, and E. Zeiger, Kinetic properties of the blue light response of stomata, *Proc. Natl. Acad. Sci. USA 82*, 8019–8023, 1985.

895 Baskin, T. I., W. R. Briggs, and M. Iino, Can lateral redistribution of auxin account for phototropism in maize coleoptiles? *Plant Physiol. 81*, 306–309, 1986.

903 Shimazaki, K., M. Iino, and W. Zeiger, Blue light–dependent proton extusion by guard-cell protoplasts of *Vicia faba*, *Nature 319*, 324–326, 1986.

920 Zeiger, E., M. Iino, and T. Ogawa, The blue light response of stomata: pulse kinetics and some mechanistic implications, *Photochem. Photobiol. 42*, 759–763, 1985.

Lon S. Kaufman

866A Kaufman, L. S., J. C. Watson, W. R. Briggs, and W. F. Thompson, Photoregulation of nuclear-encoded transcripts: blue-light regulation of specific transcript abundance, in *Molecular Biology of the Photosynthetic Apparatus*, K. Steinbeck, *et al.*, 367–372, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York, 1985.

894 Thompson, W. F., L. S. Kaufman, and J. C. Watson, Induction of plant gene expression by light, *BioEssays Vol. 3, No. 4*, 153–159, 1986.

901 Kaufman, L. S., L. Roberts, W. R. Briggs, and W. F. Thompson, Phytochrome control of specific mRNA levels in developing pea buds: kinetics of accumulation, reciprocity and escape kinetics of the low fluence response, *Plant Physiol. 81*, 1033–1038, 1986.

902 Kaufman, L. S., J. C. Watson, and W. F. Thompson, Light regulated changes in DNAse I hypersensitive sites in the rRNA genes of *Pisum sativum, Proc. Natl. Acad. Sci. USA*, in press.

914 Watson, J. C., L. S. Kaufman, and W. F. Thompson, Developmental regulation of cytosine methylation in the nuclear ribosomal RNA genes of *Pisum sativum, J. Mol. Biol.*, in press.

Peggy G. Lemaux

905 Conley P., P. Lemaux, T. L. Lomax, and A. R. Grossman, Genes encoding major light-harvesting polypeptides are clustered on the genome of the cyanobacteria *Fremyella diplosiphon, Proc. Natl. Acad. Sci. USA 83*, 3924–3928, 1986.

951 Grossman, A. R., P. G. Lemaux, and P. B. Conley, Regulated synthesis of phycobilisome components, *Photochem. Photobiol.*, in press.

Jacob Levitt

918 Levitt, J., Recovery of turgor by wilted, excised cabbage leaves in absence of water uptake: a new factor in drought acclimation, *Plant Physiol. 82*, 147–153, 1986.

Terri L. Lomax

862 Lomax, T. L., and R. J. Mehlhorn, Determination of osmotic volumes and pH gradients of plant membrane and lipid vesicles using ESR spectroscopy, *Biochim. Biophys. Acta 821*, 106–114, 1985.

905 Conley P., P. Lemaux, T. L. Lomax, and A. R. Grossman, Genes encoding major light-harvesting polypeptides are clustered on the genome of the cyanobacteria *Fremyella diplosiphon, Proc. Natl. Acad. Sci. USA 83*, 3924–3928, 1986.

Neil O. Polans

869 Polans, N. O., N. F. Weeden, and W. F. Thompson, Inheritance, organization, and mapping of *rbcS* and *cab* multigene families in pea, *Proc. Natl. Acad. Sci. USA 82*, 5083–5087, 1985.

874 Polans, N. O., N. Weeden, and W. F. Thompson, The distribution and inheritance and linkage relationships of ribosomal DNA spacer length variation in pea, *Theor. Appl. Genet. 72*, 289–295, 1986.

Linda Roberts

901 Kaufman, L. S., L. Roberts, W. R. Briggs, and W. F. Thompson, Phytochrome control of specific mRNA levels in developing pea buds: kinetics of accumulation, reciprocity and escape kinetics of the low fluence response, *Plant Physiol. 81*, 1033–1038, 1986.

Siegrid Schoch

933 Schoch, S., and J. S. Brown, The action of chlorophyllase on chlorophyll-protein complexes, *J. Plant Physiol.*, in press.

Arindam Sen

873 Williams, W. P., A. Sen, and D. C. Fork, Selective photobleaching of PS1-related chlorophylls in heat-stressed pea chloroplasts, *Photosyn. Res. 10*, 75–92, 1986.

James R. Shinkle

878 Shinkle, J. R., and W. R. Briggs, Physiological mechanism of the auxin-induced increase in light sensitivity of phytochrome-mediated growth responses in *Avena* coleoptile sections, *Plant Physiol. 79*, 349–356, 1985.

896 Shinkle, J. R., and W. R. Briggs, Optimization of red light–induced elongation in *Avena* coleoptile sections and properties of the phytochrome-mediated growth response, *Plant Cell Environ. 9*, 165–173, 1986.

897 Shinkle, J. R., Photobiology of phytochrome-mediated growth responses in sections of stem tissue from etiolated oats and corn, *Plant Physiol. 81*, 533–537, 1986.

David B. Stern

889 Stern, D. B. and K. J. Newton, Isolation of plant mitochondrial RNA, in *Methods of Enzymology Vol. 118, Plant Molecular Biology*, A. Weissbach and H. Weissbach, eds., pp. 488–496, Academic Press, New York, 1986.

906 Stern, D. B., A. Bang, and W. F. Thompson, The watermelon mitochondrial URF-1 gene: evidence for a complex structure, *Curr. Genet. 10*, 857–869, 1986.

924 Stern, D. B., and J. D. Palmer, Tripartite mitochondrial genome of spinach: physical structure, mitochondrial gene mapping, and locations of transposed chloroplast DNA sequences, *Nucl. Acids Res. 14*, No. 14, 1986.

William F. Thompson

866A Kaufman, L. S., J. C. Watson, W. R. Briggs, and W. F. Thompson, Photoregulation of nu-

clear-encoded transcripts: blue-light regulation of specific transcript abundance, in *Molecular Biology of the Photosynthetic Apparatus*, K. Steinbeck, *et al.*, eds, pp. 367–372, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York, 1986.

869 Polans, N. O., N. F. Weeden, and W. F. Thompson, The inheritance, organization, and mapping of *rbcS* and *cab* multigene families in pea, *Proc. Natl. Acad. Sci. USA 82*, 5083–5087, 1985.

872 Watson, J. C., and W. F. Thompson, Purification and restriction analysis of plant nuclear DNA, *Methods Enzymol. 118*, 57–75, 1986.

874 Polans, N. O., N. Weeden, and W. F. Thompson, Distribution and inheritance and linkage relationships of ribosomal DNA spacer length variance in pea, *Theor. Appl. Genet. 72*, 289–295, 1986.

888 Flavell, R. B., D. B. Smith, and W. F. Thompson, Chromosome architecture: the distribution of recombination sites, the structure of ribosomal DNA loci and the multiplicity of sequences containing inverted repeats, in *Molecular Form and Function of the Plant Genome*, L. van Vloten-Doting, G. S. P. Groot, and T. C. Hall, eds., pp. 1–14, Plenum Pub., New York, 1985.

894 Thompson, W. F., L. S. Kaufman, and J. C. Watson, Induction of plant gene expressions by light, *Bioessays Vol. 3, No. 4*, 153–159, 1986.

901 Kaufman, L. S., L. Roberts, W. R. Briggs, and W. F. Thompson, Phytochrome control of specific mRNA levels in developing pea buds: kinetics of accumulation, reciprocity and escape kinetics of the low fluence response, *Plant Physiol. 81*, 1033–1038, 1986.

902 Kaufman, L. S., J. C. Watson, and W. F. Thompson, Light regulated changes in DNAse I hypersensitive sites in the rRNA genes of *Pisum sativum, Proc. Natl. Acad. Sci. USA*, in press.

906 Stern, D. B., A. Bang, and W. F. Thompson, The watermelon mitochondrial URF-1 gene: evidence for a complex structure, *Curr. Genet. 10*, 857–869, 1986.

914 Watson, J. C., L. S. Kaufman, and W. F. Thompson, Developmental regulation of cytosine methylation in the nuclear ribosomal RNA genes of *Pisum sativum, J. Mol. Biol.*, in press.

928 Dobres, M. S., R. C. Elliott, J. C. Watson, and W. F. Thompson, A phytochrome regulated pea transcript encodes ferredoxin, *Plant Mol. Biol.*, in press.

939 Jorgenson, R. A., R. E. Cuellar, and W. F. Thompson, Structure and variation in ribosomal RNA genes of peas. Characterization of a cloned rDNA repeat and chromosomal rDNA variants, *Plant Mol. Biol.*, in press.

John C. Watson

866A Kaufman, L. S., J. C. Watson, W. R. Briggs, and W. F. Thompson, Photoregulation of nuclear-encoded transcripts: blue-light regulation of specific transcript abundance, in *Molecular Biology of the Photosynthetic Apparatus*, K. Steinbeck, *et al.*, eds., pp. 367–372, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York, 1985.

872 Watson, J. C., and W. F. Thompson, Purification and restriction analysis of plant nuclear DNA, *Methods Enzymol. 118*, 57–75, 1986.

894 Thompson, W. F., L. S. Kaufman, and J. C. Watson, Induction of plant gene expressions by light, *Bioessays Vol. 3, No. 4*, 153–159, 1986.

902 Kaufman, L. S., J. C. Watson, and W. F. Thompson, Light regulated changes in DNAse I hypersensitive sites in the rRNA genes of *Pisum sativum, Proc. Natl. Acad. Sci. USA*, in press.

914 Watson, J. C., L. S. Kaufman, and W. F. Thompson, Developmental regulation of cytosine methylation in the nuclear ribosomal RNA genes of *Pisum sativum, J. Mol. Biol.*, in press.

928 Dobres, M. S., R. C. Elliott, J. C. Watson, and W. F. Thompson, A phytochrome regulated pea transcript encodes ferredoxin, *Plant Mol. Biol.*, in press.

Ian Woodrow

929 Woodrow, I., Control of the rate of photosynthetic carbon dioxide fixation, *Biochim. Biophys. Acta 851*, 181–192, 1986.

DEVELOPMENTAL BIOLOGY RESEARCH GROUP

Roy J. Britten

—— Britten, R. J., and E. H. Davidson, Hybridisation strategy, in *Nucleic Acid Hybridisation: A Practical Approach*, B. D. Hames and S. J. Higgins, eds., Information Retrieval Ltd., Oxford, England, 1985.

—— Katula, K. S., B. R. Hough-Evans, C. N. Flytzanis, A. P. McMahon, R. R. Franks, R. J. Britten, and E. H. Davidson, A sea urchin gene transfer system, in *Banbury Report 20: Genetic Manipulation of the Early Mammalian Embryo*, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York, 1985.

—— Britten, R. J., Intraspecies genomic variation, in *Genetics, Development, and Evo-*

lution, J. P. Gustafson *et al.*, eds., Plenum Pub., New York, 1986.
—— Britten, R. J., Rates of DNA sequence evolution differ between taxonomic groups, *Science 231*, 1393–1398, 1986.
—— Lee, J. J., F. J. Calzone, R. J. Britten, R. C. Angerer, and E. H. Davidson, Activation of sea urchin actin genes during embryogenesis: measurement of transcript accumulation from five different genes in *Strongylocentrotus purpuratus*, *J. Mol. Biol. 188*, 173–183, 1986.
—— Hwu, H. R., J. W. Roberts, E. H. Davidson, and R. J. Britten, Insertion and/or deletion of many repeated DNA sequences in human and higher ape evolution, *Proc. Natl. Acad. Sci. USA 83*, 3875–3879, 1986.

DEPARTMENT OF TERRESTRIAL MAGNETISM

Reprints of the numbered publications listed below can be obtained at no charge from the Department of Terrestrial Magnetism, 5241 Broad Branch Road, N. W., Washington, DC 20015. When ordering, please give reprint number(s).

Barbara Barreiro
4872 Cameron, K. L., M. Cameron, and B. Barreiro, Origin of voluminous Mid-Tertiary ignimbrites of the Batopilas region, Chihuahua: implications for the formation of continental crust beneath the Sierra Madre Occidental, *Geofísica Internacional 25*, 39–59, 1986.

Alan P. Boss
4819 Boss, A. P., Phase transitions in star formation, *Nature 318*, 413, 1985.
—— Boss, A. P., Bipolar flows, molecular gas disks, and the collapse and accretion of rotating interstellar clouds, *Astrophys. J.*, in press.
—— Boss, A. P., Formation of the moon, *The Geograph. Mag.*, in press.
—— Boss, A. P., The lowest mass stars, *Sci. Reporter*, in press.
4821 Boss, A. P., The origin of the moon, *Science 231*, 341–345, 1986.
4839 Boss, A. P., Protoearth mass shedding and the origin of the moon, *Icarus 66*, 330–340, 1986.
4871 Boss, A. P., Protostellar formation in rotating, interstellar clouds, V. Nonisothermal collapse and fragmentation, *Astrophys. J. Suppl. Ser. 62*, 519–552, 1986.
4874 Boss, A. P., Theoretical determination of the minimum protostellar mass, in *Astrophysics of Brown Dwarfs*, M. Kafatos, R. S. Harrington, and S. P. Maran, eds., pp. 206–211, Cambridge University Press, New York, 1986.
—— Boss, A. P., Theory of collapse and protostar formation, in *Summer School on Interstellar Processes*, D. Hollenbach and H. Thronson, eds., D. Reidel Publ. Co., Dordrecht, The Netherlands, in press.
—— Boss, A. P., and W. Benz, Origin of the moon, *La Recherche*, in press.
4852 Boss, A. P., and S. J. Peale, Dynamical constraints on the origin of the moon, in *Origin of the Moon*, W. K. Hartmann, R. J. Phillips, and G. J. Taylor, eds., pp. 59–102, Lunar and Planetary Institute, Houston, Texas, 1986.
4867 Boss, A. P., and I. S. Sacks, High spatial resolution models of time-dependent, layered mantle convection, *Geophys. J. Roy. Astron. Soc. 87*, 241–264, 1986.
4834 Durisen, R. H., R. A. Gingold, J. E. Tohline, and A. P. Boss, Dynamic fission instabilities in rapidly rotating n = 3/2 polytropes: a comparison of results from finite-difference and smoothed particle hydrodynamics codes, *Astrophys. J. 305*, 281–308, 1986.

Louis Brown
4840 Barschall, H. H., and L. Brown, Early estimates of the strength of the nuclear spin-orbit force, *Found. Phys. 16*, 115–124, 1986.
4841 Brown, L., F. Tera, J. N. Valette-Silver, M. J. Pavich, J. Klein, and R. Middleton, Application of ^{10}Be to the study of erosion and sediment transport, in *Proceedings of the Fourth Federal Interagency Sedimentation Conference*, Vol. 1, Sect. 4, pp. 10–19, Sedimentation Sub-committee of the Interagency Advisory Committee on Water Data, U. S. Department of the Interior, Geological Survey, Washington, D. C., 1986.
4863 Pavich, M. J., L. Brown, J. Harden, J. Klein, and R. Middleton, ^{10}Be distribution in soils from Merced River terraces, California, *Geochim. Cosmochim. Acta 50*, 1727–1735, 1986.
4830 Tera, F., L. Brown, J. Morris, I. S. Sacks, J. Klein, and R. Middleton, Sediment incorporation in island-arc magmas: Inferences from ^{10}Be, *Geochim. Cosmochim. Acta 50*, 535–550, 1986.
4870 Valette-Silver, J. N., L. Brown, J. Klein, and R. Middleton, Detection of erosion events using ^{10}Be profiles: example of the impact of agriculture on soil erosion in the Chesapeake Bay area (USA), *Earth Planet. Sci. Lett. 80*, 82–90, 1986.

David Burstein
4835 Burstein, D., V. C. Rubin, W. K. Ford, Jr., and B. C. Whitmore, Is the distribution of mass

within spiral galaxies a function of galaxy environment? *Astrophys. J. 305*, L11–L14, 1986.

Richard W. Carlson

4843 Hart, W. K., S. A. Mertzman, and R. W. Carlson, Late Cenozoic volcanic geology of the Jordan Valley–Owyhee River region, southeastern Oregon, in *Field Guidebook, Rocky Mountain Section* (38th annual meeting held in Boise, Idaho), 28 pp., Rocky Mountain Section, Geological Society of America, Boise, Idaho, 1985.

4842 Silver, P. G., R. W. Carlson, P. Bell, and P. Olson, Mantle structure and dynamics, *Eos, Trans. Amer. Geophys. U. 66*, 1193–1198, 1985.

—— Carlson, R. W., Geochemistry of the subcontinental mantle, in *Yearbook of Science and Technology*, McGraw-Hill Co., New York, in press.

—— Carlson, R. W., and W. K. Hart, Miocene flood basalt volcanism in the northwestern United States, in *Continental Flood Basalts*, J. D. Macdougall, ed., D. Reidel Publ. Co., Dordrecht, The Netherlands, in press.

—— Dudás, F. Ö., R. W. Carlson, and D. H. Eggler, Regional mid-Proterozoic enrichment of the subcontinental mantle source of igneous rocks from central Montana, *Geology*, in press.

—— Hart, W. K., and R. W. Carlson, Tectonic controls on magma genesis and evolution in the northwestern United States, *J. Volcanol. Geotherm. Res.*, in press, 1986.

Winston W. Chan

—— Silver, P. G., and W. W. Chan, Observations of body-wave multipathing from broadband seismograms: evidence for lower-mantle slab penetration beneath the Sea of Okhotsk, *J. Geophys. Res. 91*, in press.

Robin Ciardullo

—— Ford, H. C., O. Dahari, G. H. Jacoby, P. C. Crane, and R. Ciardullo, Bubbles and braided jets in galaxies with compact radio nuclei, *Astrophys. J. (Lett.)*, in press.

Timothy J. Clarke

—— James, D. E., T. J. Clarke, and R. P. Meyer, A study of seismic reflection imaging using microearthquake sources, *Tectonophysics*, in press.

J. Peter Davis

—— Davis, J. P., Local eigenfrequency and its uncertainty inferred from fundamental spheroidal mode frequency shifts, *Geophys. J. Roy. Astron. Soc.*, in press.

4851 Davis, J. P., and I. H. Henson, Validity of the great circular average approximation for inversion of normal mode measurements, *Geophys. J. Roy. Astron. Soc. 85*, 69–92, 1986.

Francis Ö. Dudás

—— Dudás, F. Ö., R. W. Carlson, and D. H. Eggler, Regional mid-Proterozoic enrichment of the subcontinental mantle source of igneous rocks from central Montana, *Geology*, in press.

Lina M. Echeverría

4833 Echeverría, L. M., and B. G. Aitken, Pyroclastic rocks: another manifestation of ultramafic volcanism on Gorgona Island, Colombia, *Contrib. Mineral. Petrol. 92*, 428–436, 1986.

Sonia Esperança

4822 Esperança, S., and Z. Garfunkel, Ultramafic xenoliths from the Mt. Carmel area (Karem Maharal Volcano), Israel, *Lithos 19*, 43–49, 1986.

4865 Esperança, S., and J. R. Holloway, The origin of the high-K latites from Camp Creek, Arizona: constraints from experiments with variable fO_2 and a_{H_2O}, *Contrib. Mineral. Petrol. 93*, 504–512, 1986.

W. Kent Ford, Jr.

4835 Burstein, D., V. C. Rubin, W. K. Ford, Jr., and B. C. Whitmore, Is the distribution of mass within spiral galaxies a function of galaxy environment? *Astrophys. J. 305*, L11–L14, 1986.

4824 Giovanelli, R., M. P. Haynes, V. C. Rubin, and W. K. Ford, Jr., UGC 12591: the most rapidly rotating disk galaxy, *Astrophys. J. 301*, L7–L11, 1986.

4838 Rubin, V. C., and W. K. Ford, Jr., On the ratio of [NII]/Hα in the nucleus of M33 and in the nuclei of other galaxies, *Astrophys. J. 305*, L35–L37, 1986.

John A. Graham

4849 Alvarez, H., L. Bronfman, R. Cohen, G. Garay, J. Graham, and P. Thaddeus, Sandqvist 187: a dense molecular cloud in Norma, *Astrophys. J. 300*, 756–765, 1986.

4850 Graham, J. A., Objects associated with low-mass star formation in the Gum nebula, *Astrophys. J. 302*, 352–362, 1986.

4873 Graham, J. A., Summary: Opportunities for research with small telescopes, in *Instrumentation and Research Programmes for Small Telescopes* (International Astronomical Union Symposium 118, Christchurch, New Zealand, 1985), J. B. Hearnshaw and P. L. Cottrell, eds., pp. 475–478, D. Reidel Publ. Co., Dordrecht, The Netherlands, 1986.

4825 Humphreys, R. M., and J. A. Graham, The M supergiants in NGC 300, *Astron. J. 91*, 522–529, 1986.

Stanley R. Hart

4828 Morris, J. D., and S. R. Hart, Isotopic and incompatible element constraints on the genesis of island arc volcanics from Cold Bay and Amak Island, Aleutians, and implications for mantle structure: reply to a critical comment

Department of Terrestrial Magnetism staff, July 1986. First row (left to right): Nelson McWhorter, Glenn Poe, George Wetherill, Wendy Foard, Ines Cifuentes, Patricia Kenyon; second row: John Smith, Peter Davis, Julie Morris, Fouad Tera, Leah Monta, Sonia Esperança, Mary Coder; third row: Kent Ford, Steven Shirey, Terry Stahl, Gary Bors, Gary Heldt, Louis Brown, Dorothy Dillin, Bennie Harris, Richard W. Carlson; fourth row: Alan Linde, Robin Ciardullo, Hiroki Sato, Timothy Clarke, Michael Acierno, David James, Paul Silver, François Schweizer, Gui-zhong Qi, Nino Simoni, Diglio Simoni; top row: John Schneider, Selwyn Sacks, Alan Boss, Ole Stecher, John Emler, William Key, Thomas Aldrich, John Graham, Georg Bartels, Michael Seemann. (Absent: Richard C. Carlson, David Dalton, Janice Dunlap, Deidre Hunter, Akiwata Mayi-Sawyer, Ben Pandit, Michael Rich, Vera Rubin.)

by M. R. Perfit and R. W. Kay, *Geochim. Cosmochim. Acta 50*, 483–487, 1986.

William K. Hart

____ Carlson, R. W., and W. K. Hart, Miocene flood basalt volcanism in the northwestern United States, in *Continental Flood Basalts*, J. D. Macdougall, ed., D. Reidel Publ. Co., Dordrecht, The Netherlands, in press.

4843 Hart, W. K., S. A. Mertzman, and R. W. Carlson, Late Cenozoic volcanic geology of the Jordan Valley–Owyhee River region, southeastern Oregon, in *Field Guidebook, Rocky Mountain Section* (38th annual meeting held in Boise, Idaho), 28 pp., Rocky Mountain Section, Geological Society of America, Boise, Idaho, 1985.

____ Hart, W. K., and R. W. Carlson, Tectonic controls on magma genesis and evolution in the northwestern United States, *J. Volcanol. Geotherm. Res.*, in press, 1986.

Deidre A. Hunter

4844 Hunter, D. A., and J. S. Gallagher III, Infrared colors of blue irregular galaxies, *Astron. J. 90*, 1457–1463, 1985.

4845 Hunter, D. A., and J. S. Gallagher III, Irregular galaxies with extended HI emission, *Astron. J. 90*, 1789–1795, 1985.

4854 Hunter, D. A., and J. S. Gallagher III, Star-forming properties and histories of dwarf irregular galaxies: down but not out, *Astrophys. J. Suppl. Ser. 58*, 533–560, 1985.

4864 Gallagher, J. S., III, and D. A. Hunter, UBV colors of Virgo cluster irregular galaxies, *Astron. J. 92*, 557–566, 1986.

4836 Hunter, D. A., and J. S. Gallagher III, Stellar populations and star formation in irregular

galaxies, *Publ. Astron. Soc. Pac. 98*, 5–28, 1986.

4829 Hunter, D. A., F. C. Gillett, J. S. Gallagher III, W. L. Rice, and F. J. Low, IRAS observations of a small sample of blue irregular galaxies, *Astrophys. J. 303*, 171–185, 1986.

4831 Hunter, D. A., V. C. Rubin, and J. S. Gallagher III, Optical rotation velocities and images of the spiral galaxy NGC 3198, *Astron. J. 91*, 1086–1090, 1986.

Emi Ito

4827 Ito, E., and R. J. Stern, Oxygen- and strontium-isotopic investigations of subduction zone volcanism: the case of the Volcano Arc and the Marianas Island Arc, *Earth Planet. Sci. Lett. 76*, 312–320, 1986.

—— Ito, E., W. M. White, and C. Göpel, The O, Sr, Nd and Pb isotope geochemistry of MORB, *Chem. Geol.*, in press.

David E. James

—— James, D. E., T. J. Clarke, and R. P. Meyer, A study of seismic reflection imaging using microearthquake sources, *Tectonophysics*, in press.

Patricia M. Kenyon

4858 Kenyon, P. M., and D. L. Turcotte, Morphology of a delta prograding by bulk sediment transport, *Geol. Soc. Amer. Bull. 96*, 1457–1465, 1985.

David C. Koo

4853 Koo, D. C., Field galaxy evolution: short overview, prospects, and SAFER proposal, in *Astronomy from Measuring Machines*, I. N. Reid and P. C. Hewett, eds., pp. 112–117, Royal Greenwich Observatory, East Sussex, England, 1984.

—— Koo, D. C., Multicolor photometry of field galaxies to $B \sim 24$, *Astrophys. J. 311*, in press.

4846 Koo, D. C., R. G. Kron, and K. M. Cudworth, Quasars to $B > 22.5$ in Selected Area 57: a catalog of multicolor photometry, variability, and astrometry, *Publ. Astron. Soc. Pacific 98*, 285–306, 1986.

4826 Koo, D. C., R. G. Kron, D. Nanni, D. Trevese, and A. Vignato, A multicolor photometric catalog of galaxies and stars in the field of the rich cluster II ZW 1305.4+2941 at $z = 0.24$, *Astron. J. 91*, 478–493, 1986.

Typhoon Lee

4823 Lee, T., and F. Tera, The meteoritic chromium isotopic composition and limits for radioactive ^{53}Mn in the early solar system, *Geochim. Cosmochim. Acta 50*, 199–206, 1986.

Alan T. Linde

4860 Johnston, M. J. S., R. D. Borcherdt, and A. T. Linde, Short-period strain (0.1–10^5s): near-source strain field for an earthquake (M_L 3.2) near San Juan Bautista, California, *J. Geophys. Res. 91*, 11,497–11,502, 1986.

—— Johnston, M. J. S., A. T. Linde, M. T. Gladwin, and R. D. Borcherdt, Fault failure with moderate earthquakes, *Tectonophysics*, in press.

Stanley A. Mertzman

4843 Hart, W. K., S. A. Mertzman, and R. W. Carlson, Late Cenozoic volcanic geology of the Jordan Valley–Owyhee River region, southeastern Oregon, in *Field Guidebook, Rocky Mountain Section* (38th annual meeting held in Boise, Idaho), 28 pp., Rocky Mountain Section, Geological Society of America, Boise, Idaho, 1985.

Julie D. Morris

—— Morris, J., R. S. Harmon, F. Tera, L. Lopez-Escobar, J. Klein, and R. Middleton, ^{10}Be and Pb-isotope evidence for sediment subduction in the southern Andes, 33–42°S, *Chem. Geol.*, in press.

4828 Morris, J. D., and S. R. Hart, Isotopic and incompatible element constraints on the genesis of island arc volcanics from Cold Bay and Amak Island, Aleutians, and implications for mantle structure: reply to a critical comment by M. R. Perfit and R. W. Kay, *Geochim. Cosmochim. Acta 50*, 483–487, 1986.

4830 Tera, F., L. Brown, J. Morris, I. S. Sacks, J. Klein, and R. Middleton, Sediment incorporation in island-arc magmas: inferences from ^{10}Be, *Geochim. Cosmochim. Acta 50*, 535–550, 1986.

Vera C. Rubin

4835 Burstein, D., V. C. Rubin, W. K. Ford, Jr., and B. C. Whitmore, Is the distribution of mass within spiral galaxies a function of galaxy environment? *Astrophys. J. 305*, L11–L14, 1986.

4824 Giovanelli, R., M. P. Haynes, V. C. Rubin, and W. K. Ford, Jr., UGC 12591: the most rapidly rotating disk galaxy, *Astrophys. J. 301*, L7–L11, 1986.

4831 Hunter, D. A., V. C. Rubin, and J. S. Gallagher III, Optical rotation velocities and images of the spiral galaxy NGC 3198, *Astron. J. 91*, 1086–1090, 1986.

—— Rubin, V. C., Constraints on the dark matter from optical rotation curves, in *Dark Matter in the Universe* (International Astronomical Union Symposium 117, Princeton, New Jersey, 1985), J. Knapp and J. Kormendy, eds., D. Reidel Publ. Co., Dordrecht, The Netherlands, in press.

4859 Rubin, V. C., Dark matter in the universe, in *Highlights of Astronomy*, Vol. 7, J.-P. Swings, ed., pp. 27–38, D. Reidel Publ. Co., Dordrecht, The Netherlands, 1986.

4869 Rubin, V. C., What's the matter in spiral galaxies? in *Highlights of Modern Astrophys-*

ics: Concepts and Controversies (symposium held in honor of Ed Salpeter), S. L. Shapiro and S. A. Teukolsky, eds., pp. 269–297, John Wiley & Sons, Inc., New York, 1986.

4855 Rubin, V. C., Women's work: for women in science, a fair shake is still elusive, *Science 86, 7*, 58–65, 1986.

4838 Rubin, V. C., and W. K. Ford, Jr., On the ratio of [NII]/Hα in the nucleus of M33 and in the nuclei of other galaxies, *Astrophys. J. 305*, L35–L37, 1986.

—— Whitmore, B. C., D. B. McElroy, F. Schweizer, and V. C. Rubin, Distribution of dark matter in polar-ring galaxies, in *Dark Matter in the Universe*, (International Astronomical Union Symposium 117, Princeton, New Jersey, 1985), J. Knapp and J. Kormendy, eds., D. Reidel Publ. Co., Dordrecht, The Netherlands, in press.

I. Selwyn Sacks

4867 Boss, A. P., and I. S. Sacks, High spatial resolution models of time-dependent, layered mantle convection, *Geophys. J. Roy. Astron. Soc. 87*, 241–264, 1986.

4866 Snoke, J. A., and I. S. Sacks, Seismic modelling of lateral heterogeneity at the base of the mantle, *Geophys. J. Roy. Astron. Soc. 86*, 801–814, 1986.

4830 Tera, F., L. Brown, J. Morris, I. S. Sacks, J. Klein, and R. Middleton, Sediment incorporation in island-arc magmas: inferences from ^{10}Be, *Geochim. Cosmochim. Acta 50*, 535–550, 1986.

Hiroki Sato

4856 Sato, H., and M. H. Manghnani, Ultrasonic measurements of V_p and Q_p: relaxation spectrum of complex modulus on basalt melts, *Phys. Earth Planet. Interiors 41*, 18–33, 1985.

4861 Manghnani, M. H., H. Sato, and C. S. Rai, Ultrasonic velocity and attenuation measurements on basalt melts to 1500°C: role of composition and structure in the visoelastic properties, *J. Geophys. Res. 91*, 9333–9342, 1986.

4857 Sato, H., High temperature a.c. electrical properties of olivine single crystal with varying oxygen partial pressure: implications for the point defect chemistry, *Phys. Earth Planet. Interiors 41*, 269–282, 1986.

4862 Sato, H., M. H. Manghnani, B. R. Lienert, and A. Weiner, Effects of sample-electrode interface polarization on the electrical properties of partially molten rock, *J. Geophys. Res. 91*, 9325–9332, 1986.

François Schweizer

4820 Schweizer, F., Colliding and merging galaxies, *Science 231*, 227–234, 1986.

—— Whitmore, B. C., D. B. McElroy, F. Schweizer, and V. C. Rubin, Distribution of dark matter in polar-ring galaxies, in *Dark Matter in the Universe*, (International Astronomical Union Symposium 117, Princeton, New Jersey, 1985), J. Knapp and J. Kormendy, eds., D. Reidel Publ. Co., Dordrecht, Holland, The Netherlands, in press.

—— Whitmore, B. C., D. B. McElroy, and F. Schweizer, The shape of the dark halo in polar-ring galaxies, *Astrophys. J. 314*, in press.

Steven B. Shirey

—— Shirey, S. B., J. L. Banner, and G. N. Hanson, Cation-exchange column calibration for Sr and the REE by EDTA titration, *Isotope Geoscience*, in press.

—— Shirey, S. B., J. F. Bender, and C. H. Langmuir, Three-component chemical and isotopic heterogeneity near the oceanographer transform, Mid-Atlantic Ridge: evidence for recycling of continental lithosphere, *Nature*, in press.

—— Shirey, S. B., and G. N. Hanson, Mantle heterogeneity and crustal recycling in Archean granite-greenstone belts: evidence from Nd isotopes and trace elements in the Rainy Lake area, Ontario, *Geochim. Cosmochim. Acta 50*, in press.

—— Southwick, D. L., K. J. Schulz, R. W. Ojakangas, R. L. Bauer, S. B. Shirey, and G. N. Hanson, Archean granite greenstone terrane, Lake Superior Region, in *Precambrian: Conterminous U.S., The Decade of North American Geology* series, Vol. C-2, J. C. Reed, Jr. *et al.*, eds., Geological Society of America, Boulder, Colorado, in press, 1987.

Paul G. Silver

4842 Silver, P. G., R. W. Carlson, P. Bell, and P. Olson, Mantle structure and dynamics, *Eos, Trans. Amer. Geophys. U. 66*, 1193–1198, 1985.

4837 Riedesel, M. A., T. H. Jordan, A. F. Sheehan, and P. G. Silver, Moment-tensor spectra of the 19 Sept. 85 and 21 Sept. 85 Michoacan, Mexico earthquakes, *Geophys. Res. Lett. 13*, 609–612, 1986.

—— Silver, P. G., and W. W. Chan, Observations of body-wave multipathing from broadband seismograms: evidence for lower-mantle slab penetration beneath the Sea of Okhotsk, *J. Geophys. Res. 91*, in press.

J. Arthur Snoke

4866 Snoke, J. A., and I. S. Sacks, Seismic modelling of lateral heterogeneity at the base of the mantle, *Geophys. J. Roy. Astron. Soc. 86*, 801–814, 1986.

Robert J. Stern

4827 Ito, E., and R. J. Stern, Oxygen- and strontium-isotopic investigations of subduction zone volcanism: the case of the Volcano Arc and the Marianas Island Arc, *Earth Planet. Sci. Lett. 76*, 312–320, 1986.

Linda L. Stryker

4818 Stryker, L. L., G. S. DaCosta, and J. R. Mould, The main-sequence turnoff of the old SMC globular cluster NGC 121, *Astrophys. J. 298*, 544–559, 1985.

4868 Smith, H. A., and L. L. Stryker, Anomalous Cepheids in the Sculptor dwarf galaxy, *Astron. J. 92*, 328–334, 1986.

4832 Smith, H. A., and L. L. Stryker, Spectroscopy of c-type RR Lyrae stars in the globular cluster NGC 6638, *Publ. Astron. Soc. Pac. 98*, 453–456, 1986.

Fouad Tera

4841 Brown, L., F. Tera, J. N. Valette-Silver, M. J. Pavich, J. Klein, and R. Middleton, Application of ^{10}Be to the study of erosion and sediment transport, in *Proceedings of the Fourth Federal Interagency Sedimentation Conference*, Vol. 1, Sect. 4, pp. 10–19, Sedimentation Sub-committee of the Interagency Advisory Committee on Water Data, U. S. Department of the Interior, Geological Survey, Washington, D. C., 1986.

4823 Lee, T., and F. Tera, The meteoritic chromium isotopic composition and limits for radioactive ^{53}Mn in the early solar system, *Geochim. Cosmochim. Acta 50*, 199–206, 1986.

—— Morris, J., R. S. Harmon, F. Tera, L. Lopez-Escobar, J. Klein, and R. Middleton, ^{10}Be and Pb-isotope evidence for sediment subduction in the southern Andes, 33–42°S, *Chem. Geol.*, in press.

4830 Tera, F., L. Brown, J. Morris, I. S. Sacks, J. Klein, and R. Middleton, Sediment incorporation in island-arc magmas: inferences from ^{10}Be, *Geochim. Cosmochim. Acta 50*, 535–550, 1986.

J. Nathalie Valette-Silver

4841 Brown, L., F. Tera, J. N. Valette-Silver, M. J. Pavich, J. Klein, and R. Middleton, Application of ^{10}Be to the study of erosion and sediment transport, in *Proceedings of the Fourth Federal Interagency Sedimentation Conference*, Vol. 1, Sect. 4, pp. 10–19, Sedimentation Sub-committee of the Interagency Advisory Committee on Water Data, U. S. Department of the Interior, Geological Survey, Washington, D. C., 1986.

4870 Valette-Silver, J. N., L. Brown, J. Klein, and R. Middleton, Detection of erosion using ^{10}Be profiles: example of the impact of agriculture on soil erosion in the Chesapeake Bay area (USA), *Earth Planet. Sci. Lett. 80*, 82–90, 1986.

George W. Wetherill

4847 Wetherill, G. W., Accumulation of the terrestrial planets and implications concerning lunar origin, in *Origin of the Moon*, W. K. Hartmann, R. J. Phillips, and G. J. Taylor, eds., pp. 519–550, Lunar and Planetary Institute, Houston, Texas, 1986.

—— Wetherill, G. W., Dynamical relationships between asteroids, meteorites, and Apollo-Amor objects, in *Diffuse Matter in the Solar System* (Conference Proceedings), Royal Society of London, in press.

4848 Wetherill, G. W., Meteorites: Unexpected Antarctic chemistry, *Nature 319*, 357–358, 1986.

—— Wetherill, G. W., Mercury may be a collision fragment, in *Mercury*, C. R. Chapman, F. Vilas, and M. S. Matthews, eds., University of Arizona Press, Tucson, in press.

William M. White

—— Ito, E., W. M. White, and C. Göpel, The O, Sr, Nd and Pb isotope geochemistry of MORB, *Chem. Geol.*, in press.

Bradley C. Whitmore

4835 Whitmore, B. C., D. B. McElroy, F. Schweizer, and V. C. Rubin, Distribution of dark matter in polar-ring galaxies, in *Dark Matter in the Universe*, (International Astronomical Union Symposium 117, Princeton, New Jersey, 1985), J. Knapp and J. Kormendy, eds., D. Reidel Publ. Co., Dordrecht, The Netherlands, in press.

—— Whitmore, B. C., D. B. McElroy, and F. Schweizer, The shape of the dark halo in polar-ring galaxies, *Astrophys. J. 314*, in press.

Allan H. Wilson

—— Armstrong, N. V., A. H. Wilson, and D. R. Hunter, The Nsuze, Pongola sequence, South Africa: geochemical evidence for Archaean volcanism in a continental setting, *Precambrian Res.*, in press.

MOUNT WILSON AND LAS CAMPANAS OBSERVATORIES

Limited reprint supplies are available only for references preceded by an asterisk. Please order by reprint number. Address requests to the Editor, Mount Wilson and Las Campanas Observatories, 813 Santa Barbara Street, Pasadena, CA, 91101-1292.

Halton C. Arp

—— Arp, H. C., and B. F. Madore, *A Catalogue of Southern Peculiar Galaxies and Associations*, Vols. I and II, Cambridge University Press, in press.

3012 Arp, H., Relation of the jet in M87 to nearby

galaxies in the Virgo cluster, *J. Astrophys. Astron. (India) 7*, 71–75, 1986.
2880 Arp, H., A corrected velocity for the local standard of rest by fitting to the mean redshift of local group galaxies, *Astron. Astrophys. 156*, 207–212, 1986.
*2752 Arp, H., and O. Duhalde, Quasars near NGC 520, *Publ. Astron. Soc. Pac. 97*, 1149–1157, 1985.
2958 Stocke, J. T., J. Liebert, G. Schmidt, I. M. Gioia, T. Maccaro, R. E. Schild, D. Maccagni, and H. C. Arp, Optical and radio properties of X-ray selected BL Lacertae objects, *Astrophys. J. 298*, 619–629, 1985.
*2965 Sulentic, J. W., and H. Arp, Evidence for interaction in two discordant redshift pairs of galaxies, *Astrophys. J. 297*, 572–581, 1985.
2832 Arp, H., and A. Sandage, Spectra of the two brightest objects in the amorphous galaxy NGC 1569: superluminous young star clusters—or stars in a nearby peculiar galaxy? *Astron. J. 90*, 1163–1171, 1985.

Todd A. Boroson
2895 Leibert, J. W., T. A. Boroson, and M. S. Giampapa, New spectrophotometry of the extremely cool proper motion star LHS 2924, *Astrophys. J.*, in press.
3011 Fillmore, J., T. A. Boroson, and A. Dressler, Internal kinematics of spiral galaxies: gas and stellar rotation curves and dispersion profiles, *Astrophys. J. 302*, 208–233, 1986.
—— Margon, B., T. A. Boroson, G. A. Chanan, I. B. Thompson, and D. P. Schneider, Spectroscopy of six x-ray selected BL Lacertae candidates, *Publ. Astron. Soc. Pac.*, in press.

John E. Boyden
*3008 Chapman, G. A., and J. E. Boyden, Solar irradiance variations derived from magnetograms, *Astrophys. J. (Lett.) 302*, L71–L73, 1986.

David H. Bruning
2993 Bruning, D. H., and B. LaBonte, Variations of the asymmetry of disk-integrated solar line profiles, *Solar Phys. 97*, 1–7, 1985.

Belva Campbell
2987 Campbell, B., and S. E. Persson, Optical images of star formation regions, *Canadian J. Phys. 64*, 387–391, 1986.
2990 Campbell, B., Deep optical imaging of star forming regions with bipolar outflows, *Proceedings of Conference on Masers, Molecules, and Mass Outflows in Star Forming Regions, May 15–16, 1985*, A. D. Haschick, ed., Haystack Observatory, Massachusetts, in press.
2989 Campbell, B., S. E. Persson, and P. J. McGregor, Images of star-forming regions. I. Optical and radio morphology of the bipolar outflow source GL 490, *Astrophys. J. 305*, 336–352, 1986.

Gary A. Chapman
*3008 Chapman, G. A., and J. E. Boyden, Solar irradiance variations derived from magnetograms, *Astrophys. J. (Lett.) 302*, L71–L73, 1986.

Gary S. Da Costa
3003 Da Costa, G. S., and K. C. Freeman, The dynamics of 47 Tucanae, *Proceedings of IAU Symposium No. 1213, The Dynamics of Star Clusters*, J. Goodman and P. Hut, eds., pp. 69–72, D. Reidel Publ. Co., Dordrecht, The Netherlands, 1985.

Alan Dressler
3018 Dressler, A., D. Lynden-Bell, D. Burstein, R. Davies, S. M. Faber, G. Wegner, and R. Terlevich, Spectroscopy and photometry of elliptical galaxies. I. New distance estimator, *Astrophys. J.*, in press.
3009 Burstein, D., R. L. Davies, A. Dressler, S. M. Faber, D. Lynden-Bell, R. Terlevich, and G. Wegner, Elliptical galaxies and non-uniformities in the Hubble flow, in *Galaxy Distances and Deviations from Universal Expansion* (Proceedings from the NATO Advanced Study Institute held January 13–17, 1986), B. F. Madore, and R. B. Tully, eds., pp. 123–130, D. Reidel Publ. Co., The Netherlands, 1986.
2972 Dressler, A., Studies of cluster galaxies at large lookback times, in *Spectral Evolution of Galaxies*, Astrophys. and Space Science Library v. 122 (Proceedings of the Fourth Workshop of the Advanced School of Astronomy of the "Ettore Majorana" Centre for Scientific Culture, Erice, Italy), C. Choisi and A. Renzini, eds., pp. 375–389, D. Reidel Publ. Co., The Netherlands, 1986.
*2996 Dressler, A., P. L. Schechter, and J. A. Rose, The mass of the isolated elliptical NGC 720 as determined from the dynamics of its companions, *Astron. J. 91*, 1058–1061, 1986.
3011 Fillmore, J. A., T. A. Boroson, and A. Dressler, Internal kinematics of spiral galaxies: gas and stellar rotation curves and dispersion profiles, *Astrophys. J. 302*, 208–233, 1986.
*2964 Dressler, A., The morphological types and orbits of H I–deficient spirals in clusters of galaxies, *Astrophys. J. 301*, 35–43, 1986.
*2974 Bothun, G. D., and A. Dressler, Blue disk galaxies in the Coma cluster: analogs to z = 0.5 cluster members? *Astrophys. J. 301*, 57–64, 1986.
—— Windhorst, R. A., A. Dressler, and D. C. Koo, Ultradeep optical identifications and spectroscopy of faint radio galaxies, in *IAU Symposium No. 124, Observational Cosmology*, G. Burbidge and L. Z. Fang, eds., D. Reidel Publ. Co., The Netherlands, in press.

Douglas K. Duncan
—— Kemp, J. C., G. D. Henson, D. J. Kraus, I. S. Beardsley, L. C. Carroll, and D. K. Duncan,

Variable polarization and activity in Arcturus, *Astrophys. J. (Lett.) 301*, L35–L38, 1986.

2891 Baliunas, S. L., J. H. Horne, A. Porter, D. K. Duncan, J. Frazer, H. Lanning, A. Misch, J. Mueller, R. W. Noyes, D. Soyumer, A. H. Vaughan, and L. Woodard, Time-series measurements of chromospheric Ca II H and K emission in cool stars and the search for differential rotation, *Astrophys. J. 294*, 310–325, 1985.

Wendy L. Freedman

—— Freedman, W. L., The distribution of young stars in nearby galaxies, in *Luminous Stars and Associations in Galaxies* (IAU Symposium No. 116), C. W. H. de Loore *et al.*, eds., pp. 61–80, D. Reidel Publ. Co., Dordrecht, The Netherlands, 1986.

3013 Freedman, W. L., Recent CCD observations of Cepheids in nearby galaxies: a progress report, in *Galaxy Distances and Deviations from Universal Expansion* (Proceedings from the NATO Advanced Study Institute, held January 13–17, 1986), B. F. Madore and R. B. Tully, eds., pp. 21–24, D. Reidel Publ. Co., Dordrecht, The Netherlands, 1986.

—— Freedman, W. L., M33: radial distributions and a comparison of its global luminosity function with other nearby galaxies, in *Spectral Evolution of Galaxies*, Astrophys. and Space Science Library v. 122 (Proceedings of the Fourth Workshop of the Advanced School of Astronomy of the "Ettore Majorana" Centre for Scientific Culture, Erice, Italy, March 12–22, 1985), C. Chiosi and A. Renzini, eds., pp. 183–192, D. Reidel Publ. Co., Dordrecht, The Netherlands, 1986.

*2968 Freedman, W. L., Blue-to-red ratios and Wolf-Rayet stars in M33, *Astron. J. 90*, 2499–2507, 1985.

2960 Freedman, W. L., The upper end of the stellar luminosity function for a sample of nearby resolved late-type galaxies, *Astrophys. J. 299*, 74–84, 1985.

*2963 Carlberg, R. G., and W. L. Freedman, Dissipative models of spiral galaxies, *Astrophys. J. 298*, 486–492, 1985.

*2970 Freedman, W. L., G. R. Grieve, and B. F. Madore, BVRI photometry of extragalactic Cepheids and new insights for the distance scale, *Astrophys. J. Suppl. Ser. 59*, 311–321, 1985.

Edmond H. Giraud

2975 Giraud, E., A two-color Tully-Fisher relation, *Astron. Astrophys.*, in press.

2966 Giraud, E., The dependence of the Tully-Fisher relation on morphological type, *Astrophys. J.*, in press, 1986.

2969 Giraud, E., CCD imaging of the QSO-galaxy pair PKS 1327-206, ESO 1327-2041, *Astron. Astrophys. (Research Note) 161*, pp. 206–208, 1986.

2979 Giraud, E., Galaxy morphology, surface brightness, and the Tully-Fisher relation, *Astron. Astrophys. Letters*, in press.

*2943 Giraud, E. H., A color dependence in the distance moduli derived from the B and H band Tully-Fisher relations, *Astron. Astrophys. 155*, 283–290, 1986.

*2944 Giraud, E., The distance moduli from the B-band Tully-Fisher relation and the velocity field, *Astrophys. J. 301*, 7–16, 1986.

2940 Giraud, E., An apparent increase of the Hubble constant with velocities of the determining galaxies, *Astron. Astrophys. 153*, 125–129, 1985.

Michael D. Gregg

—— Bertola, F., M. D. Gregg, J. E. Gunn, and A. Oemler, Jr., The stellar population of NGC 6166, *Astrophys. J. 303*, 624–628, 1986.

Roger Griffin

3007 Griffin, R., and R. Griffin, The Be II λ3130 A region in the spectra of Vega and Sirius, *Astron. Astrophys. 149*, 437–441, 1985.

Jerome Kristian

3019 van Gorkom, J. H., P. L. Schechter, and J. Kristian, H I maps of S0 galaxies with polar rings, *Astrophys. J.*, in press.

2971 Mould, J., and J. Kristian, The stellar population in the halos of M31 and M33, *Astrophys. J. 305*, pp. 591–599, 1986.

William E. Kunkel

—— Irwin, M. J., W. E. Kunkel, and S. Demers, A blue stellar population in the HI bridge between the two Magellanic Clouds, *Nature 318*, 160–161, 1985.

—— Demers, S., W. E. Kunkel, and M. J. Irwin, Automated photometry of NGC 3109, *Astron. J. 90*, 1967, 1985.

S. Eric Persson

—— Geballe, T. R., and S. E. Persson, Emission from CO bandheads in young stellar objects, *Astrophys. J.*, in press.

2987 Campbell, B., and S. E. Persson, Optical images of star formation regions, *Canadian J. Phys. 64*, 387–391, 1986.

2982 Persson, S. E., High density gas in bipolar outflow sources and active galactic nuclei, *Canadian J. Phys. 64*, 421–425, 1986.

2989 Campbell, B., S. E. Persson, and P. J. McGregor, Images of star-forming regions. I. Optical and radio morphology of the bipolar outflow source GL 490, *Astrophys. J. (Lett.) 303*, 336–352, 1986.

—— Soifer, B. T., D. B. Sanders, G. Neugebauer, G. E. Danielson, C. J. Lonsdale, B. F. Madore, and S. E. Persson, The luminosity function and space density of the most luminous galaxies in the IRAS survey, *Astrophys. J. (Lett.) 303*, L41–L44, 1986.

2991 Geballe, T. R., S. E. Persson, T. Simon, C.

The new Echelle spectrograph and its makers, in Stephen Shectman's lab at the Observatories (May 1986). Front row (left to right): Bob Georgen, Phil Friswold, Harvey Crist; back row: Estuardo Vasquez, Shectman, Jill Bechtold, Chris Price, Steve Knapp.

J. Lonsdale, and P. J. McGregor, Comparison of 2.1 and 3.8 micron line profiles of shocked H_2 in the Orion Molecular Cloud, *Astrophys. J. 302*, 693–700, 1986.

2992 Elias, J. H., K. Matthews, G. Neugebauer, and S. E. Persson, Type I supernovae in the infrared and their use as distance indicators, *Astrophys. J. 296*, 379–389, 1985.

Allan Sandage

3021 Sandage, A., and Fouts, G., New subdwarfs. VI. Kinematics of 1125 high proper motion stars and the collapse of the Galaxy, *Astron. J.*, in press.

—— Tammann, G. A., B. Binggeli, and A. Sandage, Studies of the Virgo cluster. VI. The velocity distributions, *Astron. J.*, in press.

3005 Sandage, A., The population concept, globular clusters, subdwarfs, ages, and the collapse of the Galaxy, *Annu. Rev. Astron. Astrophys. 24*, in press.

2980 Sandage, A., The redshift-distance relation. IX. Perturbation of the very nearby velocity field by the local group, *Astrophys. J. 307*, 1–19, in press.

2973 Sandage, A., Star formation rates, galaxy morphology, and the Hubble sequence, *Astron. Astrophys. 161*, 89–101, 1986.

2981 Sandage, A., Brightest stars in galaxies as distance indicators, in *Luminous stars and associations in galaxies* (IAU Symposium No. 116), C. W. H. de Loore *et al.*, eds., pp. 31–45, D. Reidel Publ. Co., Dordrecht, The Netherlands, 1986.

—— Sandage, A., The classification and evolutionary sequence of galaxies, in *Proceedings of Paris Workshop on Dwarf Galaxies*, in press.

2950 Sandage, A., and G. A. Tammann, The dynamical parameters of the expanding universe as they constrain homogenous world models with and without λ, in *Inner Space Outer Space: The Interface between Cosmology and Particle Physics*, Edward Kolb *et al.*, eds., pp. 41–64, University of Chicago Press, 1986.

2994 Sandage, A., and C. Kowal, New subdwarfs. IV. UBV photometry of 1690 high proper motion stars, *Astron. J. 91*, 1140–1188, 1986.

2998 Fouts, G., and Sandage, A., New subdwarfs. V. Radial velocities for 889 high-proper-motion stars measured with the Mt. Wilson 100-inch telescope, *Astron. J. 91*, 1189–1208, 1986.

2986 Sandage, A., The brightest stars in nearby galaxies. VII. The Pegasus and Leo A Im V dwarfs, *Astron. J. 91, 496–506, 1986.*

Paul L. Schechter

3019 van Gorkom, J. H., P. L. Schechter, and J. Kristian, H I maps of S0 galaxies with polar rings, *Astrophys. J.*, in press.

2996 Dressler, A., P. L. Schechter, and J. A. Rose, The mass of the isolated elliptical NGC 720 as determined from the dynamics of its companions, *Astron. J. 91*, 1058–1061, 1986.

Thomas Y. Steiman-Cameron

2977 Steiman-Cameron, T. Y., and H. R. Johnson, Red giant model atmospheres. IV. Colors of K and M giant models, *Astrophys. J. 301*, 868–876, 1986.

Nicholas B. Suntzeff

2999 Suntzeff, N. B., M. Aaronson, E. W. Olszewski, and K. M. Cook, The abundances and velocities of the Leo dwarf spheroidals, *Astron. J. 91*, 1091–1095, 1986.

2937 Gilliland, R. L., E. Kemper, and N. Suntzeff, WZ Sagittae: Time-resolved spectroscopy during quiescence, *Astrophys. J. 301*, 252–261, 1986.

2984 Suntzeff, N. B., E. Friel, A. Klemola, R. P. Kraft, and J. A. Graham, The stellar population of the Small Magellanic Cloud near NGC 121. I. The mean metallicity, metallicity spread, and radial velocity of SMC halo giants, *Astron. J. 91*, 275–289, 1986.

—— Dominy, J. F., G. Wallerstein, and N. B. Suntzeff, Abundances of carbon, nitrogen, and oxygen and their isotopes in the atmospheres of four SC stars, *Astrophys. J. 300*, 325–338, 1986.

2978 Suntzeff, N. B., Carbon abundances in the Ursa Minor dwarf spheroidal galaxy, in *Proceedings of the ESO workshop on Production and Distribution of C, N, O Elements, held 13–15 May 1985*, I. J. Danziger *et al.*, eds., pp. 83–86, ESO, Munich, 1985.

2985 Aaronson, M., G. Gordon, J. Mould, E. Olszewski, and N. Suntzeff, The extended giant branch of the Andromeda II dwarf spheroidal galaxy, *Astrophys. J. (Lett.) 296*, L7–L11, 1985.

Ian B. Thompson

2976 Thompson, I. B., D. N. Brown, and J. D. Landstreet, The evolution of the magnetic fields of Ap stars: magnetic observations of stars in the Scorpio-Centaurus association, *Astrophys. J.*, in press.

—— Margon, B., T. A. Boroson, G. A. Chanan, I. B. Thompson, and D. P. Schneider, Spectroscopy of six x-ray selected BL Lacertae candidates, *Publ. Astron. Soc. Pac.*, in press.

Rogier A. Windhorst

—— Oort, M. J. A., P. Katgert, F. W. M. Steeman, and R. A. Windhorst, VLA high resolution observations of weak LBDS radio galaxies, *Astron. Astrophys.*, in press.

—— Windhorst, R. A., Is the upturn in the source counts caused by primeval radio galaxies? in *Highlights in Astronomy*, IAU Joint Discussion No. 4, "Radio Astronomy and Cosmology," J.-P. Swings, ed., pp. 355–366, D. Reidel Publ. Co., Dordrecht, The Netherlands, 1986.

3010 Windhorst, R. A., D. C. Koo, and H. Spinrad, Constraints on the ages of distant giant elliptical radio galaxies, in *Galaxy Distances and Deviations from Universal Expansion* (Proceedings from the NATO Advanced Study Institute held January 13–17, 1986, B. F. Madore and R. B. Tully, eds., pp. 197–202, D. Reidel Publ. Co., Dordrecht, The Netherlands, 1986.

—— Oort, M. J. A., and R. A. Windhorst, A very deep Westerbork survey of a field previously observed with the VLA, *Astron. Astrophys. 145*, 405–424, 1985.

—— Katgert-Merkelijn, J. K., J. G. Robertson, R. A. Windhorst, and P. Katgert, A Westerbork survey of the Einstein X-ray Observatory deep survey areas. I. The 0.6 and 1.4 GHz catalogues, source counts, and spectral index distributions, *Astron. Astrophys. Suppl. Ser. 61*, 517–535, 1985.

—— Windhorst, R. A., The cosmological evolution of radio sources, in *Reports on Astronomy*, Transactions of the IAU Vol. XIX, F. M. West, ed., pp. 681–694, D. Reidel Publ. Co., Dordrecht, The Netherlands, 1985.

—— Windhorst, R. A., A. Dressler, and D. C. Koo, Ultradeep optical identifications and spectroscopy of faint radio galaxies, in *IAU Symposium No. 124, Observational Cosmology*, G. Burbidge and L. Z. Fang, eds., D. Reidel Publ. Co., Dordrecht, The Netherlands, in press.

GEOPHYSICAL LABORATORY

Reprints of the numbered publications listed below are available at no charge from the Librarian, Geophysical Laboratory, 2801 Upton St., N.W., Washington, DC 20008. Please give reprint number(s) when ordering.

Andrew Y. Au

1965 Au, A. Y., and R. M. Hazen, Polyhedral modeling of the elastic properties of corundum (α-Al_2O_3) and chrysoberyl (Al_2BeO_4), *Geophys. Res. Lett. 12*, 725–728, 1985.

1975 Hazen, R. M., and A. Y. Au, High-pressure crystal chemistry of phenakite (Be_2SiO_4) and bertrandite ($Be_4Si_2O_7(OH)_2$), *Phys. Chem. Minerals 13*, 69–78, 1986.

1991 Hazen, R. M., A. Y. Au, and L. W. Finger, High-pressure crystal chemistry of beryl ($Be_3Al_2Si_6O_{18}$) and euclase ($BeAlSiO_4OH$), *Amer. Mineral. 71*, 977–984, 1986.

H. L. Barnes

—— Giże, A. P., and H. L. Barnes, The organic geochemistry of two Mississippi Valley–type lead-zinc deposits, *Econ. Geol.*, in press.

Peter M. Bell

1962 Sharma, S. K., H. K. Mao, P. M. Bell, and

J. A. Xu, Measurement of stress in diamond anvils with micro-Raman spectroscopy, *J. Raman Spectros. 16*, 350–352, 1985.

1968 Mao, H. K., J. Xu, and P. M. Bell, Calibration of the ruby pressure gauge to 800 kbar under quasihydrostatic conditions, *J. Geophys. Res. 91, B5*, 4673–4676, 1986.

1971 Jephcoat, A. P., H. K. Mao, and P. M. Bell, The static compression of iron to 78 GPa with rare gas solids as pressure-transmitting media, *J. Geophys. Res. 91, B5*, 4677–4684, 1986.

1972 Hemley, R. J., H. K. Mao, P. M. Bell, and S. Akimoto, Lattice vibrations of high-pressure SiO_2 phases: Raman spectrum of synthetic stishovite, *Physica B 139–140*, 455–457, 1986. (No reprints available.)

1974 Bell, P. M., H. K. Mao, and R. J. Hemley, Observations of solid H_2, D_2, and N_2 at pressures around 1.5 megabar at 25°C, *Physica B 139–140*, 16–20, 1986.

1984 Xu, J. A., H. K. Mao, and P. M. Bell, High pressure ruby and diamond fluorescence: observations at 0.21 to 0.55 terapascal, *Science 232*, 1404–1406, 1986.

1988 Bell, P. M., J. Xu, and H. K. Mao, Static compression of gold and copper and calibration of the ruby pressure scale to pressures to 1.8 megabars, in *Shock Waves in Condensed Matter: Proceedings of the Fourth American Physical Society (APS) Topical Conference on Shock Waves in Condensed Matter, July 22–25, 1985, Spokane, Washington*, Y. Gupta, ed., pp. 125–130, Plenum Pub., New York, 1986.

1998 Ross, M., H. K. Mao, P. M. Bell, and J. Xu, The equation of state of dense argon: a comparison of shock and static studies, *J. Chem. Phys. 85*, 1028–1033, 1986. (No reprints available.)

—— Silver, P. G., R. W. Carlson, P. Bell, and P. Olson, Mantle structure and dynamics, *Eos, Trans. Amer. Geophys. U.*, 1193–1198, 1986.

—— Jephcoat, A. P., H. K. Mao, and P. M. Bell, Operation of the megabar diamond-anvil cell, in *Hydrothermal Experimental Techniques*, H. L. Barnes and G. Ulmer, eds., chapter 19, Wiley-Interscience, New York, in press.

1996 Hemley, R. J., H. K. Mao, P. M. Bell, and B. O. Mysen, Raman spectroscopy of SiO_2 glass at high pressure, *Phys. Rev. Lett. 57*, 747–750, 1986.

Nabil Z. Boctor

1982 Boctor, N. Z., and H. S. Yoder, Jr., Petrology of some melilite-bearing rocks from Cape Province, Republic of South Africa: relationship to kimberlites, *Amer. J. Sci. 286*, 513–539, 1986.

—— Boctor, N. Z., and G. Kullerud, Mercury selenide stoichiometry and phase relations in the mercury–selenium system, *J. Solid State Chem. 62*, 177–183, 1986.

—— Boctor, N. Z., Y. N. Shieh, and G. Kullerud, Mercury ores from the New Idria mining district: Geochemical and stable isotope studies, *Geochim. Cosmochim. Acta.*, in press.

—— Boctor, N. Z., and G. Kullerud, Phase relations and equilibrium copolymerization in the sulfur–selenium system, *J. Solid State Chem.*, in press.

Francis R. Boyd

1969 Smith, D., and F. R. Boyd, Compositional heterogeneities in a high-temperature lherzolite nodule and implications for mantle processes, in *Mantle Xenoliths*, P. H. Nixon, ed., J. Wiley & Sons, New York, in press. (No reprints will be available.)

1978 Boyd, F. R., and J. J. Gurney, Diamonds and the African lithosphere, *Science 232*, 472–477, 1986.

2005 Boyd, F. R., and S. A. Mertzman, Composition and structure of the Kaapvaal lithosphere, southern Africa, in *Magmatic Processes: Physicochemical Principles*, B. O. Mysen, ed., Spec. Pub. No. 1, The Geochemical Society, in press.

—— Boyd, F. R., High- and low-temperature garnet peridotite xenoliths and their possible relation to the lithosphere-asthenosphere boundary beneath southern Africa, in *Mantle Xenoliths*, P. H. Nixon, ed., J. Wiley & Sons, New York, in press. (No reprints will be available.)

—— Finnerty, A. A., and F. R. Boyd, Thermobarometry for garnet peridotite xenoliths: a basis for upper mantle stratigraphy, in *Mantle Xenoliths*, P. H. Nixon, ed., J. Wiley & Sons, New York, in press. (No reprints will be available.)

C. Page Chamberlain

—— Chamberlain, C. Page, and P. C. England, The Acadian thermal history of the Merrimack Synclinorium in New Hampshire, *J. Geol. 93*, 593–602, 1985.

—— Chamberlain, C. Page, J. A. Docka, J. E. Post, and C. W. Burnham, Scapolite: alkali atom configurations, antiphase domains, and compositional variations, *Amer. Mineral. 70*, 134–140, 1985.

—— Chamberlain, C. Page, Evidence for the repeated folding of isotherms during regional metamorphism, *J. Petrol. 27*, 1–25, 1986.

—— Spear, F. S., and C. Page Chamberlain, Metamorphic and tectonic evolution of the Fall Mountain Nappa Complex and adjacent Merrimack Synclinorium, In *International Mineralogical Association Guidebook to New England*, P. Robinson *et al.*, eds., University of Massachusetts, Amherst, 1986.

2009 Chamberlain, C. Page, and P. Karabinos, Influence of deformation on pressure-temperature paths of metamorphism, *Geology*, in press.

Felix Chayes

1966 Chayes, F., Complementary ternaries as a

means of characterizing silica saturation in rocks of basaltic composition, *J. Geol. 93*, 743–747, 1985.

1976 Chayes, F., IGBADAT: A world data base for igneous petrology, *Episodes 8*, 245–251, 1985.

1983 Yoder, H. S., Jr., and F. Chayes, Linear alkali correlation in oceanic alkali basalts, *Bull. Geol. Soc. Finland 58, Part 1*, (Centennial Issue), 81–94, 1986.

2012 Chayes, F., Consistency of the two-group discriminant function in repartitioning rocks by name, in *Uses and Misuses of Statistics in the Earth Sciences (Memoir 1), International Association for Mathematical Geology*, W. B. Size, ed., Oxford University Press, in press.

Luis A. Cifuentes

—— Sharp, J. H., L. A. Cifuentes, R. B. Coffin, J. R. Pennock, and K. C. Wong, The influence of river variability on the circulation, chemistry, and microbiology of the Delaware Estuary, *Estuaries*, in press.

Julia C. Corrado

2001 Corrado, J. C., R. E. Weems, P. E. Hare, and R. K. Bambach, Capabilities and limitations of applied aminostratigraphy, as illustrated by analyses of *Mulinia lateralis* from the Late Cenozoic marine beds near Charleston, South Carolina, *South Carolina Geol. 30*, 19–46, 1986. (No reprints available.)

Donald B. Dingwell

1980 Dingwell, D. B., Viscosity-temperature relationships in the system $Na_2Si_2O_5$-$Na_4Al_2O_5$, *Geochim. Cosmochim. Acta 50*, 1261–1265, 1986.

1987 Dingwell, D. B., Volatile solubility, in *Mineralogical Association of Canada (MAC) Short Course Handbook, Volume 12*, C. M. Scarfe, ed., Chapter 4, pp. 93–129, Mineralogical Association of Canada, Ottawa, 1986. (No reprints available).

2006 Dingwell, D. B., Melt viscosities in the system $NaAlSi_3O_8$-H_2O-F_2O_{-1}, in *Magmatic Processes: Physicochemical Principles*, B. O. Mysen, ed., Spec. Pub. No. 1, The Geochemical Society, in press.

—— Dingwell, D. B., The structure and properties of fluorine-rich magmas: a review of experimental studies, *CIM Bull.*, in press.

Dingwell, D. B., and D. Virgo, Viscosity and redox equilibria in iron-bearing silicate melts: The system Na_2O-FeO-Fe_2O_3-SiO_2, *Geochim. Cosmochim. Acta*, in press.

Edward F. Duke

1992 Duke, E. F., and D. Rumble III, Textural and isotopic variations in plutonic rocks, south-central New Hampshire, *Contrib. Mineral. Petrol.*, in press.

1994 Rumble, D., III, E. F. Duke, and T. C. Hoering, Hydrothermal graphite in New Hampshire: evidence of carbon mobility during regional metamorphism, *Geology 14*, 452–455, 1986.

Michael H. Engel

—— Weinstein, S., M. H. Engel, and P. E. Hare, Enantiomeric analysis of a mixture of the protein amino acids by high performance liquid chromatography, in *Practical Protein Chemistry–A Handbook*, A. Darbe, ed., pp. 337–344, John Wiley & Sons Ltd., Chichester, 1985. (No reprints available.)

2011 Macko, S. A., M. L. F. Estep, M. H. Engel, and P. E. Hare, Kinetic fractionation of stable nitrogen during amino acid transamination, *Geochim. Cosmochim. Acta 50*, 2143–2146, 1986.

Marilyn L. F. Estep (see also: *Fogel*)

1964 Estep, M. L. F., and S. Vigg, Stable carbon and nitrogen isotope tracers of trophic dynamics in natural populations and fisheries of the Lahontan Lake system, Nevada, *Can. J. Fish. Aquat. Sci. 42*, 1712–1719, 1985.

2011 Macko, S. A., M. L. F. Estep, M. H. Engel, and P. E. Hare, Kinetic fractionation of stable nitrogen during amino acid transamination, *Geochim. Cosmochim. Acta 50*, 2143–2146, 1986.

John M. Ferry

1989 Rumble, D., III, J. M. Ferry, and T. C. Hoering, Oxygen isotope geochemistry of hydrothermally-altered synmetamorphic granitic rocks from south-central Maine, U.S.A., *Contrib. Mineral. Petrol. 93*, 420–428, 1986.

Larry W. Finger

1967 Mariathasan, J. W. E., R. M. Hazen, and L. W. Finger, Crystal structure of the high-pressure form of $BiVO_4$, *Phase Transitions 6*, 165–174, 1986.

1977 Hazen, R. M., and L. W. Finger, High-pressure and high-temperature crystal chemistry of beryllium oxide, *J. Appl. Phys. 59*, 3728–3733, 1986.

1985 Finger, L. W., R. M. Hazen, and A. M. Hofmeister, High-pressure crystal chemistry of spinel ($MgAl_2O_4$) and magnetite (Fe_3O_4): Comparisons with silicate spinels, *Phys. Chem. Minerals 13*, 215–220, 1986.

1991 Hazen, R. M., A. Y. Au, and L. W. Finger, High-pressure crystal chemistry of beryl ($Be_3Al_2Si_6O_{18}$) and euclase ($BeAlSiO_4OH$), *Amer. Mineral. 71*, 977–984, 1986.

—— Hughes, J. M., B. S. Christian, L. W. Finger, and L. L. Malinconico, McBirneyite, $Cu_3(VO_4)_2$, a new sublimate mineral from the fumaroles of Izalco Volcano, El Salvador, *J. Volcanol. Geotherm. Res.*, in press.

—— Hazen, R. M., L. W. Finger, D. K. Agrawal, H. E. McKinistry, and A. J. Perrotta, High-

temperature crystal chemistry of sodium zirconium phosphate, NZP, *J. Mat. Res.*, in press.

Anthony A. Finnerty

—— Finnerty, A. A., and F. R. Boyd, Thermobarometry for garnet peridotite xenoliths: a basis for upper mantle stratigraphy, in *Mantle Xenoliths*, P. H. Nixon, ed., J. Wiley & Sons, New York, in press. (No reprints will be available.)

Marilyn L. Fogel (see also: *Estep*)

—— Fogel, M. L., E. K. Sprague, A. P. Giże, and R. W. Frey, Diagenesis of organic matter in Georgia salt marshes, *Geochim. Cosmochim. Acta*, in press.

John D. Frantz

—— Marshall, W. L., and J. D. Frantz, Electrical conductance measurements of dilute aqueous electrolytes at temperatures to 800°C and pressures to 4000 bars; techniques and interpretations, in *Research Techniques for High-Pressure and High-Temperature, 2nd Edition*, G. C. Ulmer and H. L. Barnes, eds., John Wiley & Sons, New York, in press.

Andrew P. Giże

—— Giże, A. P., Analytical approaches to organic matter in ore deposits, in *Denver Region Exploration Geologists Symposium on "Organics and Ore Deposits,"* W. E. Dean, ed., pp. 21–32, Denver Region Exploration Geologists Society, Wheat Ridge, Colorado, 1986.

—— Giże, A. P., The development of a thermal mesophase in bitumens from high-temperature ore deposits, in *Denver Region Exploration Geologists Symposium on "Organics and Ore Deposits,"* W. E. Dean, ed., pp. 137–150, Denver Region Exploration Geologists Society, Wheat Ridge, Colorado, 1986.

—— Giże, A. P., and H. L. Barnes, The organic geochemistry of two Mississippi Valley–type lead-zinc deposits, *Econ. Geol.*, in press.

—— Fogel, M. L., E. K. Sprague, A. P. Giże, and R. W. Frey, Diagenesis of organic matter in Georgia salt marshes, *Geochim. Cosmochim. Acta*, in press.

John J. Gurney

1978 Boyd, F. R., and J. J. Gurney, Diamonds and the African lithosphere, *Science 232*, 472–477, 1986.

P. Edgar Hare

2000 Hedges, J. I., and P. E. Hare, Amino acid adsorption by clay minerals in distilled water, *Geochim. Cosmochim. Acta*, in press. (No reprints will be available.)

2001 Corrado, J. C., R. E. Weems, P. E. Hare, and R. K. Bambach, Capabilities and limitations of applied aminostratigraphy, as illustrated by analyses of *Mulinia lateralis* from the Late Cenozoic marine beds near Charleston, South Carolina, *South Carolina Geol. 30*, 19–46, 1986. (No reprints available.)

—— Weinstein, S., M. H. Engel, and P. E. Hare, Enantiomeric analysis of a mixture of the protein amino acids by high performance liquid chromatography, in *Practical Protein Chemistry–A Handbook*, A. Darbe, ed., pp. 337–344, John Wiley & Sons Ltd., Chichester, 1985. (No reprints available.)

2011 Macko, S. A., M. L. F. Estep, M. H. Engel, and P. E. Hare, Kinetic fractionation of stable nitrogen during amino acid transamination, *Geochim. Cosmochim. Acta 50*, 2143–2146, 1986.

—— Nelson, B. K., M. J. Deniro, M. J. Schoeninger, D. J. Depaolo, and P. E. Hare, Effects of diagenesis on strontium, carbon, nitrogen and oxygen concentration and isotopic composition of bone from Greenland, *Geochim. Cosmochim. Acta 50*, 1941–1949, 1986. (No reprints will be available.)

Robert M. Hazen

1965 Au, A. Y., and R. M. Hazen, Polyhedral modeling of the elastic properties of corundum (α-Al_2O_3) and chrysoberyl (Al_2BeO_4), *Geophys. Res. Lett. 12*, 725–728, 1985.

1967 Mariathasan, J. W. E., R. M. Hazen, and L. W. Finger, Crystal structure of the high-pressure form of $BiVO_4$, *Phase Transitions 6*, 165–174, 1986.

1975 Hazen, R. M., and A. Y. Au, High-pressure crystal chemistry of phenakite (Be_2SiO_4) and bertrandite ($Be_4SiO_7(OH)_2$), *Phys. Chem. Minerals 13*, 69–78, 1986.

1977 Hazen, R. M., and L. W. Finger, High-pressure and high-temperature crystal chemistry of beryllium oxide, *J. Appl. Phys. 59*, 3728–3733, 1986.

1985 Finger, L. W., R. M. Hazen, and A. M. Hofmeister, High-pressure crystal chemistry of spinel ($MgAl_2O_4$) and magnetite (Fe_3O_4): Comparisons with silicate spinels, *Phys. Chem. Minerals 13*, 215–220, 1986.

1991 Hazen, R. M., A. Y. Au, and L. W. Finger, High-pressure crystal chemistry of beryl ($Be_3Al_2Si_6O_{18}$) and euclase ($BeAlSiO_4OH$), *Amer. Mineral. 71*, 977–984, 1986.

—— Hazen, M. H., and R. M. Hazen, *The Music Men: An Illustrated History of the Band in America to 1920*, Smithsonian Institution, Washington, D.C., in press. (Will be obtainable only by purchase from the publisher.)

2003 Hazen, R. M., High-pressure crystal chemistry of chrysoberyl, Al_2BeO_4: insights on the origin of olivine elastic anisotropy, *Phys. Chem. Minerals*, in press.

—— Hazen, R. M., A useful fiction: Polyhedral modeling of mineral properties, *Amer. J. Sci.*, Wones Volume, in press.

—— Hazen, R. M., L. W. Finger, D. K. Agrawal, H. E. McKinistry, and A. J. Perrotta, High-

temperature crystal chemistry of sodium zirconium phosphate, NZP, *J. Mat. Res.*, in press.

John I. Hedges

2000 Hedges, J. I., and P. E. Hare, Amino acid adsorption by clay minerals in distilled water, *Geochim. Cosmochim. Acta*, in press. (No reprints will be available.)

Russell J. Hemley

1972 Hemley, R. J., H. K. Mao, P. M. Bell, and S. Akimoto, Lattice vibrations of high-pressure SiO_2 phases: Raman spectrum of synthetic stishovite, *Physica B 139–140*, 455–457, 1986. (No reprints available.)

1974 Bell, P. M., H. K. Mao, and R. J. Hemley, Observations of solid H_2, D_2, and N_2 at pressures around 1.5 megabar at 25°C, *Physica B 139–140*, 16–20, 1986.

1993 Hemley, R. J., H. K. Mao, and E. C. T. Chao, Raman spectrum of natural and synthetic stishovite, *Phys. Chem. Minerals 13*, 285–290, 1986.

1995 Mehl, M. J., R. J. Hemley, and L. L. Boyer, Potential-induced breathing model for the elastic moduli and high-pressure behavior of the cubic alkaline-earth oxides, *Phys. Rev. B 33*, 8685–8696, 1986.

1996 Hemley, R. J., H. K. Mao, P. M. Bell, and B. O Mysen, Raman spectroscopy of SiO_2 glass at high pressure, *Phys. Rev. Lett. 57*, 747–750, 1986.

1997 Hemley, R. J., M. D. Jackson, and R. G. Gordon, Theoretical study of the structure, lattice dynamics, and equations of state of perovskite-type $MgSiO_3$ and $CaSiO_3$, *Phys. Chem. Minerals*, in press.

—— Hemley, R. J., Pressure dependence of Raman spectra of SiO_2 polymorphs: α-quartz, coesite, and stishovite, in *High-Pressure Research in Mineral Physics*, M. H. Manghnani and Y. Syona, eds., Terra Publishers, Tokyo, in press.

—— Mao, H. K., R. J. Hemley, and E. C. T. Chao, The application of micro-Raman spectroscopy to analysis and identification of minerals in thin section, *J. Scanning Electron Microscopy*, in press.

Thomas C. Hoering

1981 Rumble, D., III, and T. C. Hoering, Carbon isotope geochemistry of graphite vein deposits from New Hampshire, U.S.A., *Geochim. Cosmochim. Acta 50*, 1239–1247, 1986.

1989 Rumble, D., III, J. M. Ferry, and T. C. Hoering, Oxygen isotope geochemistry of hydrothermally-altered synmetamorphic granitic rocks from south-central Maine, U.S.A., *Contrib. Mineral. Petrol. 93*, 420–428, 1986.

1994 Rumble, D., III, E. F. Duke, and T. C. Hoering, Hydrothermal graphite in New Hampshire: Evidence of carbon mobility during regional metamorphism, *Geology 14*, 452–455, 1986.

2013 Hoering, T. C., and V. Navale, A search for molecular fossils in the kerogen of Precambrian sedimentary rocks, *Precambrian Res.*, in press.

—— Hofmeister, A. M., T. C. Hoering, and D. Virgo, Vibrational spectroscopy of beryllium aluminosilicates: Heat capacity calculations from band assignments, *Phys. Chem. Minerals*, in press.

Anne M. Hofmeister

—— Hofmeister, A. M., and G. R. Rossman, A spectroscopic study of blue radiation coloring in plagioclase, *Amer. Mineral. 71*, 95–98, 1986.

1985 Finger, L. W., R. M. Hazen, and A. M. Hofmeister, High-pressure crystal chemistry of spinel ($MgAl_2O_4$) and magnetite (Fe_3O_4): comparisons with silicate spinels, *Phys. Chem. Minerals*, in press.

—— Hofmeister, A. M., T. C. Hoering, and D. Virgo, Mid- and far-infrared and Raman spectroscopy of beryllium aluminosilicates: use of band assignments to calculate heat capacity C_V from lattice dynamic models, *Phys. Chem. Minerals*, in press.

John M. Hughes

—— Hughes, J. M., B. S. Christian, L. W. Finger, and L. L. Malinconico, McBirneyite, $Cu_3(VO_4)_2$, a new sublimate mineral from the fumaroles of Izalco Volcano, El Salvador, *J. Volcanol. Geotherm. Res.*, in press.

T. Neil Irvine

1990 Irvine, T. N., and M. R. Sharpe, Magma mixing and the origin of stratiform oxide ore zones in the Bushveld and Stillwater Complexes, in *Metallogeny of Basic and Ultrabasic Rocks*, M. J. Gallager *et al.*, eds., pp. 183–198, Institute of Mining and Metallurgy, London, 1986. (No reprints available.)

Andrew P. Jephcoat

1971 Jephcoat, A. P., H. K. Mao, and P. M. Bell, The static compression of iron to 78 GPa with rare gas solids as pressure-transmitting media, *J. Geophys. Res. 91, B5*, 4677–4684, 1986.

—— Jephcoat, A. P., H. K. Mao, and P. M. Bell, Operation of the megabar diamond-anvil cell in *Hydrothermal Experimental Techniques*, H. L. Barnes and G. Ulmer, eds., chapter 19, Wiley-Interscience, New York, in press.

—— Jephcoat, A. P., and P. L. Olson, Is the inner core pure iron? *Nature*, in press.

Gunnar Kullerud

—— Boctor, N. Z., and G. Kullerud, Mercury selenide stoichiometry and phase relations in the mercury-selenium system, *J. Solid State Chem. 62*, 177–183, 1986.

—— Boctor, N. Z., Y. N. Shieh, and G. Kullerud, Mercury ores from the New Idria mining district: Geochemical and stable isotopes studies,

Geochim. Cosmochim. Acta., in press.
—— Boctor, N. Z., and G. Kullerud, Phase relations and equilibrium copolymerization in the sulfur-selenium system, *J. Solid State Chem.*, in press.

Ikuo Kushiro

2007 Kushiro, I., A petrological model of the upper mantle and lower crust in the Japanese arcs, in *Magmatic Processes: Physicochemical Principles*, B. O. Mysen, ed., Spec. Pub. No. 1, The Geochemical Society, in press.
—— Kushiro, I., Viscosity of partial melts in the upper mantle, *J. Geophys. Res. 91*, 9343–9350, 1986.
—— Kushiro, I., Density of basalt magmas at high pressures and its petrological application, in *Advances in Physical Geochemistry*, ("Physical Chemistry of Magmas"), L. L. Perchuk and I. Kushiro, eds., Springer-Verlag, New York, in press.

Robert W. Luth

—— Luth, R. W., and A. Boettcher, Hydrogen and the melting of silicates, *Amer. Mineral. 71*, 264–276, 1986.

Stephen A. Macko

2011 Macko, S. A., M. L. F. Estep, M. H. Engel, and P. E. Hare, Kinetic fractionation of stable nitrogen during amino acid transamination, *Geochim. Cosmochim. Acta*, in press.

Ho-kwang Mao

1962 Sharma, S. K., H. K. Mao, P. M. Bell, and J. A. Xu, Measurement of stress in diamond anvils with micro-Raman spectroscopy, *J. Raman Spectros. 16*, 350–352, 1985.
1968 Mao, H. K., J. Xu, and P. M. Bell, Calibration of the ruby pressure gauge to 800 kbar under quasihydrostatic conditions, *J. Geophys. Res. 91, B5*, 4673–4676, 1986.
1971 Jephcoat, A. P., H. K. Mao, and P. M. Bell, The static compression of iron to 78 GPa with rare gas solids as pressure-transmitting media, *J. Geophys. Res. 91, B5*, 4677–4684, 1986.
1972 Hemley, R. J., H. K. Mao, P. M. Bell, and S. Akimoto, Lattice vibrations of high-pressure SiO_2 phases: Raman spectrum of synthetic stishovite, *Physica B 139–140*, 455–457, 1986. (No reprints available.)
1974 Bell, P. M., H. K. Mao, and R. J. Hemley, Observations of solid H_2, D_2, and N_2 at pressures around 1.5 megabar at 25°C, *Physica B 139–140*, 16–20, 1986.
1984 Xu, J. A., H. K. Mao, and P. M. Bell, High pressure ruby and diamond fluorescence: observations at 0.21 to 0.55 terapascal, *Science 232*, 1404–1406, 1986.
1988 Bell, P. M., J. Xu, and H. K. Mao, Static compression of gold and copper and calibration of the ruby pressure scale to pressures to 1.8 megabars, in *Shock Waves in Condensed Matter: Proceedings of the Fourth American Physical Society (APS) Topical Conference on Shock Waves in Condensed Matter, July 22–25, 1985, Spokane, Washington*, Y. Gupta, ed., pp. 125–130, Plenum Pub., New York, 1986.
1993 Hemley, R. J., H. K. Mao, and E. C. T. Chao, Raman spectrum of natural and synthetic stishovite, *Phys. Chem. Minerals 13*, 285–290, 1986.
1998 Ross, M., H. K. Mao, P. M. Bell, and J. Xu, The equation of state of dense argon: a comparison of shock and static studies, *J. Phys. Chem. 85*, 1028–1033, 1986.
—— Jephcoat, A. P., H. K. Mao, and P. M. Bell, Operation of the megabar diamond-anvil cell in *Hydrothermal Experimental Techniques*, H. L. Barnes and G. Ulmer, eds., chapter 19, Wiley-Interscience, New York, in press.
1996 Hemley, R. J., H. K. Mao, P. M. Bell, and B. O. Mysen, Raman spectroscopy of SiO_2 glass at high pressure, *Phys. Rev. Lett. 57*, 747–750, 1986.
—— Mao, H. K., R. J. Hemley, and E. C. T. Chao, The application of micro-Raman spectroscopy to analysis and identification of minerals in thin section, *J. Scanning Electron Microscopy*, in press.

Joseph W. E. Mariathasan

1967 Mariathasan, J. W. E., R. M. Hazen, and L. W. Finger, Crystal structure of the high-pressure form of $BiVO_4$, *Phase Transitions 6*, 165–174, 1986.

Gregory E. Muncill

—— Muncill, G. E., and A. C. Lasaga, Crystal growth kinetics of plagioclase in igneous systems: I. One-atmosphere experiments and application of a simplified growth model, *Amer. Mineral.*, in press.

Bjørn Mysen

1986 Mysen, B., Structure and petrologically important properties of silicate melts relevant to natural magmatic liquids, in *Mineralogical Association of Canada (MAC) Short Course Handbook, Volume 12,*, C. M. Scarfe, ed., chapter 7, pp. 180–209, Mineralogical Association of Canada, Ottawa, 1986. (No reprints available.)
1996 Hemley, R. J., H. K. Mao, P. M. Bell, and B. O. Mysen, Raman spectroscopy of SiO_2 glass at high pressure, *Phys. Rev. Lett. 57*, 747–750, 1986.
1999 Mysen, B. O., and D. Virgo, Volatiles in silicate melts at high pressure and temperature: 1. Interactions between OH groups and Si^{4+}, Al^{3+}, Ca^{2+}, Na^{+}, and H^{+}, *Chem. Geol.*, in press.
2002 Mysen, B. O., and D. Virgo, Volatiles in

silicate melts at high pressure and temperature: 2. Water in melts along the join $NaAlO_2$-SiO_2 and a comparison of solubility mechanisms of water and fluorine, *Chem. Geol.*, in press.
2008 Mysen, B. O., Magmatic silicate melts: Relations between bulk composition, structure and properties, in *Magmatic Processes: Physicochemical Principles*, B. O. Mysen, ed., Spec. Pub. No. 1, The Geochemical Society, in press.
2010 Scarfe, C. M., B. O. Mysen, and D. Virgo, Pressure dependence of the viscosity of silicate melts, in *Magmatic Processes: Physicochemical principles*, B. O. Mysen, ed., Spec. Pub. No. 1, The Geochemical Society, in press.
—— Mysen, B. O., Relations between structure, redox equilibria of iron, and properties of magmatic liquids, in *Advances in Physical Geochemistry*, L. L. Perchuk and I. Kushiro, eds., Springer-Verlag, New York, in press.

Pascal Richet
1970 Richet, P., and Y. Bottinga, Thermochemical properties of silicate glasses and liquids: a review, *Rev. Geophys. 24*, 1–25, 1986.

Douglas Rumble III
1981 Rumble, D., III, and T. C. Hoering, Carbon isotope geochemistry of graphite vein deposits from New Hampshire, U.S.A., *Geochim. Cosmochim. Acta 50*, 1239–1247, 1986.
1989 Rumble, D., III, J. M. Ferry, and T. C. Hoering, Oxygen isotope geochemistry of hydrothermally-altered synmetamorphic granitic rocks from south-central Maine, U.S.A., *Contrib. Mineral. Petrol. 93*, 420–428, 1986.
1992 Duke, E. F., and D. Rumble III, Textural and isotopic variations in plutonic rocks, south-central New Hampshire, *Contrib. Mineral. Petrol. 93*, 409–419, 1986.
1994 Rumble, D., III, E. F. Duke, and T. C. Hoering, Hydrothermal graphite in New Hampshire: Evidence of carbon mobility during regional metamorphism, *Geology 14*, 452–455, 1986.
—— Spear, F. S., and D. Rumble III, Pressure, temperature and structural evolution of the Orfordville Belt, west-central New Hampshire, *J. Petrol.*, in press.

Christopher M. Scarfe
2010 Scarfe, C. M., B. O. Mysen, and D. Virgo, Pressure dependence of the viscosity of silicate melts, in *Magmatic Processes: Physicochemical Principles*, B. O. Mysen, ed., Spec. Pub. No. 1, The Geochemical Society, in press.

Daniel J. Schulze
1973 Schulze, D. J., Calcium anomalies in the mantle and a possible subducted metaserpentinite origin for diamonds, *Nature 319*, 483–485, 1986.

Shiv K. Sharma
1962 Sharma, S. K., H. K. Mao, P. M. Bell, and J. A. Xu, Measurement of stress in diamond anvils with micro-Raman spectroscopy, *J. Raman Spectros. 16*, 350–352, 1985.

Martin R. Sharpe
1990 Irvine, T. N., and M. R. Sharpe, Magma mixing and the origin of stratiform oxide ore zones in the Bushveld and Stillwater Complexes, in *Metallogeny of Basic and Ultrabasic Rocks*, M. J. Gallager *et al.*, eds., pp. 183–198, Institute of Mining and Metallurgy, London, 1986. (No reprints available.)

Douglas Smith
1969 Smith, D., and F. R. Boyd, Compositional heterogeneities in a high-temperature lherzolite nodule and implications for mantle processes, in *Mantle Xenoliths*, P. H. Nixon, ed., J. Wiley & Sons, New York, in press. (No reprints will be available.)

Frank S. Spear
—— Spear, F. S., and C. Page Chamberlain, Metamorphic and tectonic evolution of the Fall Mountain Nappa Complex and adjacent Merrimack Synclinorium, In *International Mineralogical Association Guidebook to New England*, P. Robinson *et al.*, eds., University of Massachusetts, Amherst, 1986.
—— Spear, F. S., and D. Rumble III, Pressure, temperature and structural evolution of the Orfordville Belt, west-central New Hampshire, *J. Petrol.*, in press.

E. Kent Sprague
—— Fogel, M. L., E. K. Sprague, A. P. Giże, and R. W. Frey, Diagenesis of organic matter in Georgia salt marshes, *Geochim. Cosmochim. Acta*, in press.

Thomas W. Stafford, Jr.
—— Stafford, T. W., Jr., A. J. T. Jull, K. Brendel, R. C. Duhamel, and D. Donahue, Study of radiocarbon dating accuracy at the University of Arizona NSF accelerator facility for radioisotope analysis, *Radiocarbon*, in press.
—— Stafford, T. W., Jr., and R. A. Tyson, Accelerator radiocarbon dates on charcoal and shell from the Del Mar Early Man site, California, *Amer. Antiq.*, in press.

David Virgo
1999 Mysen, B. O., and D. Virgo, Volatiles in silicate melts at high pressure and temperature: 1. Interactions between OH groups and Si^{4+}, Al^{3+}, Ca^{2+}, Na^{+}, and H^{+}, *Chem. Geol.*, in press.
2002 Mysen, B. O., and D. Virgo, Volatiles in silicate melts at high pressure and temperature: 2. Water in melts along the join $NaAlO_2$-

SiO_2 and a comparison of solubility mechanisms of water and fluorine, *Chem. Geol.*, in press.

2010 Scarfe, C. M., B. O. Mysen, and D. Virgo, Pressure dependence of the viscosity of silicate melts, in *Magmatic Processes: Physicochemical Principles*, B. O. Mysen, ed., Spec. Pub. No. 1, The Geochemical Society, in press.

—— Dingwell, D. B., and D. Virgo, Viscosity and redox equilibria in iron-bearing silicate melts: The system Na_2O-FeO-Fe_2O_3-SiO_2, *Geochim. Cosmochim. Acta*, in press.

—— Hofmeister, A. M., T. C. Hoering, and D. Virgo, Vibrational spectroscopy of beryllium aluminosilicates: Heat capacity calculations from band assignments, *Phys. Chem. Minerals*, in press.

Ji-an Xu

1962 Sharma, S. K., H. K. Mao, P. M. Bell, and J. A. Xu, Measurement of stress in diamond anvils with micro-Raman spectroscopy, *J. Raman Spectros. 16*, 350–352, 1985.

1968 Mao, H. K., J. Xu, and P. M. Bell, Calibration of the ruby pressure gauge to 800 kbar under quasihydrostatic conditions, *J. Geophys. Res. 91, B5*, 4673–4676, 1986.

1984 Xu, J. A., H. K. Mao, and P. M. Bell, High pressure ruby and diamond fluorescence: Observations at 0.21 to 0.55 terapascal, *Science 232*, 1404–1406, 1986.

1988 Bell, P. M., J. Xu, and H. K. Mao, Static compression of gold and copper and calibration of the ruby pressure scale to pressures to 1.8 megabars, in *Shock Waves in Condensed Matter: Proceedings of the Fourth American Physical Society (APS) Topical Conference on Shock Waves in Condensed Matter, July 22–25, 1985, Spokane, Washington*, Y. Gupta, ed., pp. 125–130, Plenum Pub., New York, in press.

1998 Ross, M., H. K. Mao, P. M. Bell, and J. Xu, The equation of state of dense argon: a comparison of shock and static studies, *J. Chem. Phys. 85*, 1028–1033, 1986. (No reprints available.)

Hatten S. Yoder, Jr.

1979 Yoder, H. S., Jr., Trends in the education of earth scientists, *J. Geol. Educ. 34*, 166–173, 1986.

1982 Boctor, N. Z., and H. S. Yoder, Jr., Petrology of some melilite-bearing rocks from Cape Province, Republic of South Africa: relationship to kimberlites, *Amer. J. Sci. 286*, 513–539, 1986.

1983 Yoder, H. S., Jr., and F. Chayes, Linear alkali correlation in oceanic alkali basalts, *Bull. Geol. Soc. Finland 58 Part 1*, (Centennial Issue), 81–94, 1986.

2004 Yoder, H. S., Jr., Potassium-rich rocks: phase analysis and heteromorphic relations, *J. Petrol. 27*, 1215–1228, 1986.

ADMINISTRATION

James D. Ebert

—— Ebert, J. D., The life sciences in a conserving society: enhancing the quality of life (in Japanese), *Bioscience and Industry 44*, 944–956, 1986.

—— Ebert, J. D., The embryogenesis of embryology (a review of *A History of Embryology: The Eighth Symposium of the British Society for Developmental Biology*, T. J. Halder *et al.*, eds., Cambridge University Press, 1986), in *Cell 47*, 159–160, 1986.

Margaret L. A. MacVicar

—— MacVicar, M. L. A., subject and overview ed. for superconducting materials, *Encyclopedia of Materials Science and Engineering*, Pergamon Press, Oxford, 1986.

—— MacVicar, M. L. A., and P. Wyatt, "Brakes," *World Book Encyclopedia*, 1986.

—— MacVicar, M. L. A., and P. Wyatt, "Carburetor," *World Book Encyclopedia*, 1986.

—— MacVicar, M. L. A., and E. Fine, "Engineering," *World Book Encyclopedia*, 1986.

PUBLICATIONS OF THE INSTITUTION

Carnegie Institution of Washington Year Book 84, viii + 198 pages, 36 illustrations, December 1985.

Carnegie Institution of Washington, informational booklet, 24 pages, 20 illustrations, September 1985.

CIW Newsletter, issued in November 1985, April 1986, and June 1986.

Perspectives in Science, 6th edition, recorded features for radio and classroom use, with resumes, January 1986.

Annual Report of the Director, Mount Wilson and Las Campanas Observatories, 1984–1985, 67 pages, 19 illustrations.

Carnegie Evening, 1986, 20 pages, 13 illustrations, May 1986.

Administrative Documents

Members of the Department of Plant Biology. Seated, bottom row, left to right: James Shinkle, Sabrina Robbins, Pamela Conley, Jeanette Brown, Grazyna Bialek-Bylka, Glenn Ford, Karen Hall, Frank Nicholson. Second row: Neal Woodbury, Anurag Sagar, Donald Thomas. Third row: David Stern, Timothy Ball, Eugenio deHostos, Brian Welsh, Peggy Lemaux. Fourth row: Lewis Feldman, Benjamin Horwitz, Loretta Tayabas, Winslow Briggs, Terri Lomax, Robin Chazdon. Fourth row: Pedro Pulido, Marta Laskowski. Fifth row: Aida Wells, Barbara Demmig. Top: Einar Ingebretsen. Standing, left to right: Engelbert Weis, Robert Guy, Christopher Field, Robert Elliot, Ulrich Kutschera, Joseph Berry, Max Seyfried, Jacob Levitt, Michael Dobres, Mary Smith, Ian Woodrow, William Thompson, John Watson, Lamont Anderson, Olle Björkman, Dodi Horvat, Salil Bose, David Fork, Malcolm Nobs (seated).

Staff Lists

DEPARTMENT OF EMBRYOLOGY

Research Staff

Donald D. Brown, Director
Douglas M. Fambrough[1]
Nina V. Fedoroff
Joseph G. Gall
Steven L. McKnight
Richard E. Pagano
Allan C. Spradling
Samuel Ward

Staff Associates

Philip Beachy[2]
Sondra G. Lazarowitz
David Schwartz[3]
Martin Snider

Research Associates (Extramural)

Bent Böving, Detroit, Michigan
Igor B. Dawid, Bethesda, Maryland
Robert L. DeHaan, Atlanta, Georgia
Douglas M. Fambrough, Baltimore, Maryland[4]
Arthur T. Hertig, Boston, Massachusetts
Irwin R. Konigsberg, Charlottesville, Virginia
Kenneth J. Muller, Miami, Florida
Ronan O'Rahilly, Davis, California
Elizabeth M. Ramsey, Washington, D.C.
Ronald H. Reeder, Seattle, Washington
Gerald M. Rubin, Berkeley, California
Yoshiaki Suzuki, Okazaki City, Japan

Postdoctoral Fellows and Grant-Supported Associates

Matthew Andrews, Fellow of the Damon Runyon–Walter Winchell Cancer Fund
Jo Ann Banks, Fellow of the National Institutes of Health (NIH)
Karen Bennett, Fellow of the NIH
Celeste Berg, Carnegie Corporation Fellow[5]
Lynn Cooley, Fellow of the Damon Runyon–Walter Winchell Cancer Fund
Martyn Darby, Research Associate, NIH grant (Brown)[5]
Patrick DiMario, American Cancer Society Fellow[6]
Lloyd Epstein, Research Associate, NIH grant (Gall)
Barbara Graves, Research Associate, NIH grant (McKnight)
Mitrick Johns, Fellow of the Pioneer Hi-Bred International, Inc.[7]
Peter Johnson, Fellow of the Damon Runyon–Walter Winchell Cancer Fund
Norman Karin, Fellow of the CIW[1]
Richard Kelley, Fellow of the NIH
Samuel Kelly, United Agriseed Fellow
Gene Leys, Fellow of the NIH
Steven L'Hernault, Fellow of the NIH
Riccardo Losa, Swiss National Science Foundation[6]
Patrick Mason, NATO Fellow and Foundation National de la Researches Sciences Fellow[8]
Terry Orr-Weaver, Fellow of the Jane Coffin Childs Memorial Fund
Mark Roth, Fellow of the Jane Coffin Childs Memorial Fund
Richard Sleight, Fellow of the NIH[9]
Richard Surosky, Fellow of the NIH[10]
Kunio Takeyasu, Research Associate, NIH grant (Fambrough)[1]
Michael Tamkun, Fellow of the Muscular Dystrophy Association[1]
William Taylor, Fellow of the NIH[11]
Steven Triezenberg, Fellow of the Helen Hay Whitney Foundation
Frank Tufaro, Fellow of the NIH
Paul Uster, Fellow of the CIW[12]
Kent Vrana, Fellow of the NIH
Alan Wolffe, Fellow of the European Molecular Biology Organization
Barry Wolitzky, Fellow of the Muscular Dystrophy Association[1]

Graduate Students

Celeste Berg, Yale University[13]
Susan Bromley, Yale University
Eric Crawford, Johns Hopkins University

Zaven Kaprielian, Johns Hopkins University[1]
Michael Koval, Johns Hopkins University
William Landschulz, Johns Hopkins University[14]
Inara Lazdins, Johns Hopkins University[15]
Suki Parks, Johns Hopkins University
Jennifer Schwartz, Johns Hopkins University
Diane Shakes, Johns Hopkins University
Barbara Sosnowski, Johns Hopkins University
Tony Ting, Johns Hopkins University
Rahul Warrior, Yale University
Steve Weinheimer, University of Washington

Supporting Staff

Betty Addison, Laboratory Helper
Ellen Cammon, Laboratory Helper[16]
Patricia Englar, Administrative Assistant
James Fenwick, Laboratory Helper
Tim Fields, Photographer[17]
Ernestine Flemmings, Laboratory Helper
Richard Grill, Photographer[18]
Vonnie Henson, Laboratory Helper
Wilson Hoerichs, Building Engineer[7]
Mary E. Hogan, Technician
Eddie Jordan, Senior Technician
Jeff Kingsbury, Technician
Robert Kingsbury, Technician
Joseph Levine, Technician
Jeffrey Malter, Technician
Ona Martin, Senior Technician
David Meloni, Technician[16]
Ronald Millar, Building Engineer[10]
Christine Murphy, Technician
Allison Pinder, Technician[19]
Earl Potts, Custodian
Ophelia Rogers, Technician[18]
Susan Satchell, Business Manager
Michael Sepanski, Technician
Delores Somerville, Senior Technician[1]
Lori Steffy, Bookkeeper/Clerk
Diane Thompson, Technician
Joe Vokroy, Machinist
Shirley Whitaker, Secretary
Gloria Wilkes, Laboratory Helper

---

[1]To July 1, 1985
[2]From April 1, 1986
[3]From September 11, 1985
[4]From July 2, 1985
[5]From April 1, 1986
[6]From October 1, 1985
[7]To September 30, 1985
[8]From November 1, 1985
[9]To December 31, 1985
[10]From October 7, 1985
[11]To July 30, 1985
[12]To February 28, 1986
[13]To March 31, 1986
[14]From August 15, 1985
[15]From July 2, 1985
[16]From December 16, 1985
[17]From June 5, 1986
[18]To June 30, 1986
[19]From January 3, 1986

DEPARTMENT OF PLANT BIOLOGY

Research Staff

Joseph A. Berry
Olle Björkman
Winslow R. Briggs, Director
Jeanette S. Brown
Christopher B. Field
David C. Fork
C. Stacy French, Director Emeritus
Arthur R. Grossman
William M. Hiesey, Emeritus
Malcolm A. Nobs, Emeritus
William F. Thompson[1]

Research Associates

Robin Chazdon[1]
Lon S. Kaufman[2]
Peggy G. Lemaux

Postdoctoral Fellows

Lamont K. Anderson, National Science Foundation Fellow[3]
Maryse A. Block[4]
Grazyna Bialek-Bylka[5]
Lise Caron[2]
Pamela B. Conley
Michael S. Dobres
Barbara Demmig[6]
Robert D. Guy
Benjamin A. Horwitz[7]
Ulrich Kutschera[8]
Terri L. Lomax, National Science Foundation Fellow[9]
Anurag O. Sagar
Max Seyfried[10]
Loverine P. Taylor, National Institutes of Health Fellow[11]
John C. Watson
Engelbert Weis[12]
Neal Woodbury, National Science Foundation Fellow[13]
Ian Woodrow, Harkness Fellow, Australian National University, Canberra[14]
Akihiko Yamagishi[15]

Graduate Students

J. Timothy Ball, Stanford University

Tobias I. Baskin, Stanford University
Eugenio L. deHostos, Stanford University
Robert L. Elliott, Stanford University
Laura S. Green, Stanford University
Marta Laskowski, Stanford University
Elizabeth Newell, Stanford University
James R. Shinkle, Stanford University[2]
David B. Stern, Stanford University[9]
Lawrence D. Talbott, Stanford University

Supporting Staff

Michael Arbuckle, Laboratory Technician[9]
Linda Austin, Laboratory Technician
J. Timothy Ball, Laboratory Technician
Glenn Ford, Research Operations Manager
Suzan M. Freas, Laboratory Manager
Karen L. B. Hall, Laboratory Manager
Dorothy B. Horvat, Laboratory Manager
Einar Ingebretsen, Electrical Engineer
Waldo Lanas, Laboratory Technician
Frank Nicholson, Senior Technician, Facilities Manager
Aviva Patel, Laboratory Technician[1]
Pedro Pulido, Technician
Sabrina E. Robbins, Laboratory Technician
Linda A. Roberts, Laboratory Technician
Connie Shih, Laboratory Technician
Mary A. Smith, Business Manager
Loretta Tayabas, Technical Typist
Donald Thomas, Technician/Horticulturist
Kallidaikurichi Venkatachalam, Laboratory Technician
Rudolph Warren, Technician
Aida E. Wells, Department Secretary
Brian M. Welsh, Mechanical Engineer

---

[1]To June 30, 1986
[2]To September 30, 1985
[3]From July 1, 1985
[4]From May 1, 1986
[5]To December 19, 1985
[6]To April 3, 1986
[7]From October 15, 1985
[8]From October 1, 1985
[9]To December 31, 1985
[10]To June 17, 1986
[11]From October 1, 1985
[12]From August 26, 1985
[13]From December 16, 1985
[14]From August 16, 1985
[15]From February 1, 1986

DEPARTMENT OF TERRESTRIAL MAGNETISM

Research Staff

L. Thomas Aldrich, Emeritus
Alan Paul Boss
Louis Brown
Richard W. Carlson
W. Kent Ford, Jr.[1]
John Graham[1,2]
David E. James
Alan T. Linde
Vera C. Rubin[1]
I. Selwyn Sacks
François Schweizer[1]
Steven B. Shirey[2]
Paul Silver
Fouad Tera
George W. Wetherill, Director

Research Associates

Robert Lee Edmonds[3]
Patricia M. Kenyon[4]
John Schneider
Linda L. Stryker[5]
Nathalie Valette-Silver[6]

Senior Fellows

Robert P. Meyer, Senior Visiting Fellow, University of Wisconsin, Madison[7]
Gui-Zhong Qi
Diglio A. Simoni V., Senior Visiting Fellow, NASA Astrophysical Observatory, Arequipa, Peru[8]

Postdoctoral Fellows

Kirk Borne[9]
W. Winston Chan[10]
Robin Ciardullo[11]
Timothy J. Clarke
J. Peter Davis[12]
Sonia Esperança
Deidre Hunter, Richard B. Roberts Fellow
Julie Morris
Michael Rich[13]
Hiroki Sato

Students and Predoctoral Fellows

Richard Aster, University of Wisconsin, Madison[14]
Ines Cifuentes, Lamont-Doherty Geological Observatory, Columbia University
David Dalton, Virginia Polytechnic Institute and State University[15]
Francis Ö. Dudás, Pennsylvania State University[16]
Vernon Green, University of Wisconsin, Madison[14]

Mark Norman, Rice University[17]
Martha Savage, University of Wisconsin, Madison[14]
Sharon Shih, University of Wisconsin, Madison[14]
Diglio A. Simoni C., The College of Wooster[18]

Supporting Staff

Michael Acierno, Computer Programmer
Georg Bartels, Instrument Maker
Gary A. Bors, Maintenance Technician
Richard C. Carlson, Word Processor Operator
Mary McDermott Coder, Editorial Assistant
Dorothy B. Dillin, Librarian
Janice Dunlap, Administrative Assistant for PASSCAL[19]
John A. Emler, Laboratory Technician
Wendy Foard, Clerk-Typist[20]
Bennie Harris, Caretaker
Gary D. Heldt, Jr., Caretaker[19]
William E. Key, Caretaker
Nelson McWhorter, Instrument Maker[21]
Leah Monta, Accounts Payable Clerk
Ben K. Pandit, Electronics Specialist
Glenn R. Poe, Electronics Research Specialist
Akiwata Mayi Sawyer, Research Assistant
Michael Seemann, Design Engineer—Mechanical, Shop Manager
John F. Smith, Caretaker[19]
Terry L. Stahl, Fiscal Officer
Mary E. White, Receptionist[22]

---

[1]Holds additional appointment as Adjunct Staff Member, Mount Wilson and Las Campanas Observatories
[2]From July 1, 1985
[3]To September 23, 1985
[4]From November 18, 1985
[5]To August 31, 1985
[6]To December 31, 1985
[7]From May 27, 1986
[8]From May 19, 1986
[9]To September 30, 1985
[10]To January 6, 1986
[11]From November 12, 1985
[12]From January 6, 1986
[13]From May 12, 1986
[14]From June 15, 1986
[15]From January 6, 1986
[16]To September 10, 1985
[17]To November 15, 1985
[18]From May 15, 1986
[19]Temporary employee
[20]From December 1, 1985
[21]From September 4, 1985
[22]To November 15, 1985

GEOPHYSICAL LABORATORY

Research Staff

Peter M. Bell
Francis R. Boyd, Jr.
Felix Chayes[1]
Larry W. Finger
Marilyn L. Fogel
John D. Frantz[2]
P. Edgar Hare
Robert M. Hazen
Thomas C. Hoering
T. Neil Irvine
Ho-kwang Mao
Bjørn O. Mysen
Douglas Rumble III[3]
David Virgo
Hatten S. Yoder, Jr., Director[4]

Distinguished Visiting Investigator

Ikuo Kushiro[5]

Keck Earth Sciences Research Scholar

Gregory E. Muncill

Postdoctoral Associates

Andrew Y. Au[6]
Anne M. Hofmeister[7]
Ji-an Xu[8]

Postdoctoral Fellows

C. Page Chamberlain[9]
Donald B. Dingwell[10]
Andrew P. Giże[11]
Russell J. Hemley
Andrew P. Jephcoat[12]
Robert W. Luth[9]
Thomas W. Stafford, Jr.

Predoctoral Fellow

L. A. Cifuentes

Supporting Staff

Andrew J. Antoszyk, Instrument Maker
Charlie A. Batten, Shop Foreman and Instrument Maker[1]

Stephen D. Coley, Sr., Instrument Maker
Roy R. Dingus, Instrument Maker
Mack C. Ferguson, Jr., Custodian[13]
David J. George, Electronics Technician
Christos Hadidiacos, Electronics Engineer
Marjorie E. Imlay, Assistant to the Director
Michael Jenkins, Secretary-Receptionist
Lavonne Lela, Librarian-Stenographer
Harvey J. Lutz, Clerk and Technician
Mabel B. Mattingly, Stenographer
Lawrence B. Patrick, Custodial Supervisor
Dolores M. Petry, Editor and Librarian[14]
David Ratliff, Jr., Custodian and Thin-Section Technician
John M. Straub, Business Manager

---

[1]Retired June 30, 1986
[2]del Duca Fellow, Centre National de la Recherche Scientifique, Nancy, from August 1, 1985
[3]Leave of absence, National Science Foundation
[4]To June 30, 1986
[5]From March 1, 1986
[6]To August 31, 1985
[7]From January 1, 1986
[8]To February 1, 1986
[9]From July 1, 1985
[10]To June 30, 1986
[11]To August 31, 1985
[12]From October 1, 1985
[13]To March 14, 1986
[14]Retired August 31, 1985

MOUNT WILSON AND LAS CAMPANAS OBSERVATORIES

Research Staff

Halton C. Arp[1]
Horace W. Babcock, Emeritus
Alan Dressler
Jerome Kristian
S. Eric Persson
George W. Preston, Director[2]
Allan Sandage[3]
Paul L. Schechter
Leonard Searle
Stephen A. Shectman
Olin C. Wilson, Emeritus

Adjunct Staff Members

W. Kent Ford, Department of Terrestrial Magnetism, CIW
John Graham, Department of Terrestrial Magnetism, CIW
Vera C. Rubin, Department of Terrestrial Magnetism, CIW
François Schweizer, Department of Terrestrial Magnetism, CIW

Las Campanas Resident Scientists

Wojciech A. Krzeminski, Resident Scientist
William E. Kunkel, Resident Scientist/Administrator

Research Associates

Douglas K. Duncan[4]
Ian B. Thompson

Postdoctoral Fellows

Jill Bechtold, Carnegie Fellow[5]
John Caldwell[6]
Belva G. Campbell
Michael D. Gregg, Carnegie Fellow
Wendy L. Freedman, Carnegie Fellow
Robert I. Jedrzejewski, U.K. SERC Fellow
Abhijit Saha, Carnegie Fellow[7]
Thomas Y. Steiman-Cameron, Carnegie Fellow[8]
Nicholas B. Suntzeff, Carnegie Las Campanas Observatory Fellow[9]
Rogier A. Windhorst, Carnegie Fellow

Predoctoral Carnegie-Chile Fellow

Fernando J. Selman, California Institute of Technology

Supporting Staff, Pasadena

John M. Adkins, Research Assistant
Maria Anderson, Manuscript Typist and Editor
Nicolette Breski, Purchasing Agent
Richard T. Black, Business Manager
John E. Boyden, Systems Programmer, Solar Physics[10]
David M. Carr, Electronics Technician[11]
Ken D. Clardy, Data Systems Manager
Maynard K. Clark, Electronics Engineer, Solar Physics[9]
Harvey W. Crist, Machinist
Carroll L. Friswold, Head, Design Group
Joan Gantz, Librarian
Robert D. Georgen, Foreman, Machine Shop
Pamela I. Gilman, Research Assistant, Solar Physics[12]
Rhea M. Goodwin, Assistant to the Director
John A. Jacobs, Electronics Technician (part-time)[13]
Basil N. Katem, Senior Research Assistant
Stephen L. Knapp, Electronics Engineer
Stephen P. Padilla, Research Assistant, Solar

Physics[12]
Frank Perez, Technical Assistant to the Director
Christopher M. Price, Electronics Engineer
William D. Qualls, Driver[13]
Delores B. Sahlin, Receptionist
Edward H. Snoddy, Designer
Jeannie M. Todd, Bookkeeper
Estuardo Vasquez, Machinist
Steven Wilson, Carpenter
Laura A. Woodard, Research Assistant/Observer

Supporting Staff, Mount Wilson

Judy L. Carr, Stewardess (part-time)[15]
James Frazer, Night Assistant/Observer
Ricardo de Leon, Steward[16]
Jean Mueller, Night Assistant/Observer[17]
Anthony Misch, Observatory Technician[18]
Donald R. Poppe, Night Assistant/Observer[8]
Eric Rawe, Observatory Technician[8]
Larry Webster, Resident Solar Observer[19]

Supporting Staff, Las Campanas

Alain Aubry T., Electronics Technician[20]
Héctor Balbontín I., Chef
Danilo Bassi A., Electronics Technician[21]
Angel Cortés L., Accountant
Oscar Duhalde C., Night Assistant
Angel Guerra F., Night Assistant
Leonel Lillo A., Carpenter
Mario Mondaca O., Guard (part-time)
Herman Olivares G., Warehouse Attendant
Ljubomir Papič, Mountain Superintendent
Alfredo Paredes Z., Equipment Operator
Fernando Peralta B., Night Assistant
Leonardo Peralta B., Driver and Purchaser
Victorino Riquelme, P., Janitor
Honorio Rojas P., Pump Operator
Pedro Rojas T., Mason
William Robinson W., Electronics Technician[22]
Luis Solis P., Electronics Technician
Mario Taquías L., Plumber
Gabriel Tolmo v., El Pino Guard
Jorge Tolmo V., El Pino Guard
Mauricio Villalobos H., Chef
Patricia Villar B., Administrative Assistant
Victor Valenzuela L., Mechanic[8]

---

[1]Leave of absence to June 30, 1986; retired June 30, 1986
[2]Director to June 30, 1986
[3]Leave of absence from October 1, 1985
[4]To January 31, 1986
[5]From December 16, 1985
[6]From August 1, 1985
[7]From October 1, 1985
[8]To August 31, 1985
[9]To December 31, 1985
[10]To September 30, 1985
[11]From July 31, 1985
[12]To October 31, 1985
[13]From February 21, 1986
[14]Retired June 30, 1986
[15]To July 20, 1985
[16]To September 1, 1985
[17]To July 1, 1985
[18]To June 4, 1986
[19]To June 30, 1986
[20]From February 1, 1986
[21]To January 1, 1986
[22]To August 15, 1985

OFFICE OF ADMINISTRATION

Lloyd H. Allen, Custodian
Cynthia T. Blagmon, Receptionist and Clerk[1]
Ray Bowers, Editor, Publications Officer
Don A. Brooks, Custodian
Cady Canapp, Administrator for Personnel and Employee Benefits
Carolyn J. Davis, Secretary
Barbara F. Deal, Administrative Assistant
James D. Ebert, President
Jacqueline Green, Secretary to the President
Joseph M. S. Haraburda, Accounting Manager
Susan E. Henderson, Systems Accountant[2]
Jill Humphreys, Receptionist and Clerk[3]
Antoinette M. Jackson, Facilities and Support Services Manager
Sherman L. E. Johnson, Payroll Supervisor
John C. Lawrence, Controller
Margaret L. Loflin, Assistant to the Vice President
Margaret L. A. MacVicar, Vice President
Susan A. Maslousky, Accountant[4]
John B. Osolnick, Systems Accountant
Patricia Parratt, Associate Editor
Arnold J. Pryor, Equal Opportunity Officer
Richard B. Sell, Accountant
Greg Silsbee, Grants and Contracts Administrator
Susan Y. Vasquez, Assistant to the President
Si-ming Wang, Student Assistant from People's Republic of China[5]

---

[1]From June 16, 1986
[2]To July 10, 1985
[3]To March 26, 1986
[4]From October 17, 1985
[5]From June 13, 1986

APPOINTMENTS IN SPECIAL SUBJECT AREAS

Roy J. Britten, Staff Member of the Institution[1]

Barbara McClintock, Distinguished Service Member of the Institution[2]

---

[1]Distinguished Carnegie Senior Research Associate, Developmental Biology Research Group, California Institute of Technology

[2]Cold Spring Harbor, New York

Visiting Investigators

DEPARTMENT OF PLANT BIOLOGY

Salil Bose, University of Madurai, India
Lewis J. Feldman, University of California, Berkeley
Marilyn Fogel, Geophysical Laboratory, CIW
Jacob Levitt, Senior Fellow, University of Minnesota
Siegrid Schoch, Senior Fellow, University of Munich, West Germany
Arindam Sen, Roswell Park Memorial Institute, Buffalo, New York
Bruce B. Stowe, Yale University

DEPARTMENT OF TERRESTRIAL MAGNETISM

Barbara Barreiro, Dartmouth College
Kenneth D. Collerson, University of Regina, Canada
Wang Enfu, State Seismological Bureau, Beijing, People's Republic of China
Jiang Guang, State Seismological Bureau, Beijing, People's Republic of China
William K. Hart, Miami University
Liu Lanbo, State Seismological Bureau, Beijing, People's Republic of China
Jacek Leliwa-Kopystynski, Polish Academy of Science, Warsaw
Stanley A. Mertzman, Franklin and Marshall College
Tsutomu Murase, Institute of Vocational Training, Sagamihara, Kanagawa, Japan
Leandro Rodriguez, Instituto Geofísico del Peru, Lima
J. Arthur Snoke, Virginia Polytechnic Institute and State University
Ole Stecher, University of Aarhus, Denmark
Glen R. Stewart, University of Virginia
Raymond Willemann, Los Alamos National Laboratory
Allan H. Wilson, University of Natal, South Africa

GEOPHYSICAL LABORATORY

B. K. Agarwala, University of Delhi, India
Denesh Agrawal, Pennsylvania State University
Jagan Akella, Lawrence Livermore Laboratories
Mary Jo Baedecker, U. S. Geological Survey
Mark Barton, University of California, Los Angeles
Lukas Baumgartner, University of Basel
Françoise Behar, Institut Français du Petrole, Rueil Malmaison, France
James Bischoff, U. S. Geological Survey
Nabil Z. Boctor, Purdue University
Luis A. Cifuentes, University of Delaware
Lloyd Currie, National Bureau of Standards
Howard W. Day, University of California, Davis

Melville P. Dickenson, Virginia Polytechnic Institute and State University
James W. Downs, Ohio State University
A. A. Finnerty, University of California, Davis
Fred Gallaraga, University of Maryland
Wen-yang Guo, Jilin University, People's Republic of China
Dong-ming Jing, Jilin University, People's Republic of China
Douglas Keith, Dartmouth College
Ronald W. L. Kimber, CSIRO, Adelaide, Australia
Julie Kokis, George Washington University
Rama Kotra, U. S. Geological Survey
Vince La Piana, Yale University
Barbara Levinson, University of Maryland
Rong-hua Li, Jilin University, People's Republic of China
Heinz A. Lowenstam, California Institute of Technology
Ian D. MacGregor, National Science Foundation
Catherine McCammon, University of British Columbia
Hugh McKinstry, Pennsylvania State University
Tsutomu Murase, Institute of Vocational Training, Japan
V. S. Nanda, University of Delhi, India
Vivek Navale, University of Maryland
Yuen-jei Pong, Jilin University, People's Republic of China
Hiroki Sato, University of Hawaii
Martha W. Schaefer, Naval Research Laboratory
Zachary Sharp, University of Michigan
Martin R. Sharpe, University of Pretoria, South Africa
E. Kent Sprague, University of Georgia
Linda Stathoplos, University of Rhode Island
Au-chin Tang, Jilin University, People's Republic of China
Louis Walter, Goddard Space Flight Center, NASA
Huei-yang Wang, Jilin University, People's Republic of China
Terry Wu, University of Maryland
Jianguo Xu, Institute of Geochemistry, Academia Sinica, People's Republic of China

MOUNT WILSON AND LAS CAMPANAS OBSERVATORIES

Thomas Albert,* University of Basel
Martin Aparicio, University of Andalucia
Dana Backman, University of Arizona
Luis H. Barrera, Catholic University of Chile
Bruno A. Binggeli, University of Basel
David A. Bohlender,* University of Western Ontario
Luzius Cameron,* University of Basel
Daniel Cerrito,* University of Basel
Marc Davis, University of California, Berkeley
Alexei Filippenko, University of California, Berkeley
Alfred Gautschy,* University of Basel
Gerard Gilmore, University of Cambridge
Perry Hacking,* Jet Propulsion Laboratory and Cornell University
Eduardo Hardy, Laval University
Hugh Harris, U. S. Naval Observatory
Robert Hill,* University of Western Ontario
Deidre Hunter, Department of Terrestrial Magnetism, CIW
John Hutchings, Dominion Astrophysical Observatory
Renee Kraan-Korteweg, University of Basel
John D. Landstreet, University of Western Ontario
Bruno Leibundgut,* University of Basel
Douglas McElroy, Space Telescope Science Institute
Jose Maza, University of Chile
Guido Munch, Max-Planck-Institut für Astronomie, Heidelburg, and Jet Propulsion Laboratory
Mario Pedreros, University of Chile
Hernan Quintana, Catholic University of Chile
Anja Schroeder,* University of Basel
R. Singer,* University of Basel
Bradford A. Smith, University of Arizona
A. Spaenhauer,* University of Basel
Gustav A. Tammann, University of Basel
Santiago Tapia, University of Arizona
Richard J. Terrile, Jet Propulsion Laboratory
Nikolaus Vogt, Catholic University of Chile
Robert West, Jet Propulsion Laboratory
George Wetherill, Department of Terrestrial Magnetism, CIW
Rosemary Wyse, University of California, Berkeley

California Institute of Technology Observers

Timothy Beers
Gregory Bothun
Judith Cohen
Christopher Impey
Barry Madore
Jeremy Mould
James Nemec
R. Michael Rich*
Wallace L. W. Sargent
Fernando J. Selman*
Charles Steidel*
John Trauger

*Graduate student

Report of the Executive Committee

To the Trustees of the Carnegie Institution of Washington

In accordance with the provisions of the By-Laws, the Executive Committee submits this report to the Annual Meeting of the Board of Trustees.

During the fiscal year ending June 30, 1986, the Executive Committee held five meetings. Accounts of these meetings have been or will be mailed to each Trustee.

A full statement of the finances and work of the Institution for the fiscal year ended June 30, 1985, appears in the Institution's *Year Book 84*, a copy of which has been sent to each Trustee. An estimate of the Institution's expenditures in the fiscal year ending June 30, 1987, appears in the budget recommended by the Committee for approval by the Board of Trustees.

The terms of the following members of the Board expire on May 9, 1986:

Philip H. Abelson
Robert G. Goelet
Caryl P. Haskins
George F. Jewett, Jr.
John D. Macomber
Charles H. Townes
Sidney J. Weinberg, Jr.

In addition, the terms of all Committee Chairmen and the following members of Committees expire on May 9, 1986:

Executive Committee

William C. Greenough
Caryl P. Haskins
Charles H. Townes

Nominating Committee

Antonia Ax:son Johnson

Finance Committee

William C. Greenough
Sidney J. Weinberg, Jr.

Employee Benefits Committee

Philip H. Abelson
William T. Coleman, Jr.
Charles H. Townes

Robert C. Seamans, Jr., *Chairman*

May 9, 1986

Abstract of Minutes

of the Eighty-Ninth Meeting of the Board of Trustees

The annual meeting of the Board of Trustees was held in the Board Room of the Administration Building on Friday, May 9, 1986. The meeting was called to order by the Chairman, William R. Hewlett.

The following Trustees were present: Philip H. Abelson, Lewis M. Branscomb, William T. Coleman, Jr., Edward E. David, Jr., John Diebold, Gerald M. Edelman, Sandra M. Faber, Robert G. Goelet, William T. Golden, William C. Greenough, Caryl P. Haskins, Richard E. Heckert, William R. Hewlett, George F. Jewett, Jr., Antonia Ax:son Johnson, William F. Kieschnick, Gerald D. Laubach, John D. Macomber, Robert M. Pennoyer, Richard S. Perkins, Robert C. Seamans, Jr., Charles H. Townes, Sidney J. Weinberg, Jr., and Gunnar Wessman. Also present were William McChesney Martin, Jr. and Garrison Norton, Trustees Emeriti, James D. Ebert, President, Margaret L. A. MacVicar, Vice President, John C. Lawrence, Controller, Susan Y. Vasquez, Assistant Secretary, and Marshall Hornblower, Counsel.

The minutes of the Eighty-Eighth Meeting were approved.

The reports of the Executive Committee, the Finance Committee, the Employee Benefits Committee, and the Auditing Committee were accepted. On the recommendation of the latter, it was resolved that Price Waterhouse & Co. be appointed as public accountants for the fiscal year ending June 30, 1986.

Section 5.8 of the By-Laws was amended. The amended language is given in the By-Laws printed on pages 179–184 of this Year Book.

On the recommendation of the Nominating Committee, Thomas N. Urban was elected a member of the Board of Trustees, and the following were reelected for terms ending in 1989: Philip H. Abelson, Robert G. Goelet, Caryl P. Haskins, George F. Jewett, Jr., John D. Macomber, Charles H. Townes, and Sidney J. Weinberg, Jr.

Richard E. Heckert was elected Chairman of the Board for a term ending in 1989 and Robert C. Seamans, Jr., was elected Vice Chairman of the Board for a term ending in 1988.

The following were elected for one-year terms: Robert C. Seamans, Jr., as Chairman of the Executive Committee; Sidney J. Weinberg, Jr., as Chairman of the Finance Committee; Robert M. Pennoyer, as Chairman of the Auditing Committee; William T. Golden, as Chairman of the Nominating Committee; and William T. Coleman, Jr., as Chairman of the Employee Benefits Committee.

Vacancies in the Standing Committees, with terms ending in 1989, were filled as follows: William C. Greenough, Caryl P. Haskins, George F. Jewett, Jr., and Gerald D. Laubach were elected members of the Executive Committee; Sidney J. Weinberg, Jr., and William C. Greenough were elected members of the Finance Committee; William F. Kieschnick was elected a member of the Nominating Committee; and William T. Coleman, Jr. was

elected a member of the Employee Benefits Committee. In addition, William R. Hewlett was elected a member of the Executive Committee for the unexpired term ending in 1987.

Dr. Seamans reported further to the Board on the deliberations of the Executive Committee at its meeting on May 8, 1986, regarding a site for the co-location of the Geophysical Laboratory and Department of Terrestrial Magnetism and adoption of the following resolution:

> *Resolved*, That, because the highest priority of the Institution in the earth and related astronomical sciences is to realize the opportunities for unique scientific collaborations and bold, new lines of scientific inquiry inherent in the intellectual collaboration of the Geophysical Laboratory and the Department of Terrestrial Magnetism, the Executive Committee
>
> 1. Authorizes the President to commission the development of an architectural schematic plan for new construction and renovation of existing structures on the Broad Branch Road site in Washington, D. C., appropriate to co-location of the Geophysical Laboratory and the Department of Terrestrial Magnetism,
> 2. Requests the President, with the close cooperation of the Directors of the Geophysical Laboratory and the Department of Terrestrial Magnetism, to work closely with the architect in the development of the schematic plan and analysis of its budget implications, for review by the Trustees in Spring of 1987, and
> 3. Requests the President, with the close cooperation of the Directors of the Geophysical Laboratory and the Department of Terrestrial Magnetism, to devise a plan and timetable for the intellectual collaboration of the two departments, and, with these two Directors, together with the Director of Mount Wilson and Las Campanas Observatories, to address the question whether the Institution should continue to maintain two separate groups of astronomers, currently in Pasadena and Washington, D. C., and
> 4. Declines the gracious and generous invitation of The Johns Hopkins University to relocate the Geophysical Laboratory and the Department of Terrestrial Magnetism to a common site on the University's Homewood campus.

The annual report of the President was accepted.

To provide for the operation of the Institution for the fiscal year ending June 30, 1987, and upon recommendation of the Executive Committee, the sum of $17,625,000 was appropriated.

Financial Statements

for the year ended June 30, 1986

CARNEGIE INSTITUTION OF WASHINGTON
TEN-YEAR FINANCIAL SUMMARY, 1977–1986
(All figures are thousands of dollars; fiscal years ended June 30)

	1986	1985	1984	1983	1982	1981	1980	1979	1978	1977
Revenues										
Interest and dividends	$10,166	$11,196	$10,224	$ 8,983	$9,100	$6,976	$6,486	$5,256	$5,019	$4,675
Other	317	163	187	241	314	197	156	306	80	338
Restricted grants, expended	5,595	5,198	4,308	4,476	4,587	3,912	2,613	1,805	1,544	1,077
Total revenues	16,078	16,557	14,719	13,700	14,001	11,085	9,255	7,367	6,643	6,090
Expenses										
Terrestrial Magnetism	2,873	2,947	2,342	2,156	2,043	1,492	1,414	1,385	1,298	1,295
Mount Wilson and Las Campanas Observatories	3,355	3,743	3,662	3,355	3,496	2,656	2,631	2,364	2,182	2,564
Geophysical Laboratory	2,399	2,391	2,204	2,096	2,434	1,724	1,595	1,512	1,406	1,295
Embryology	2,941	2,984	2,517	2,374	2,321	2,047	1,445	1,313	1,388	1,418
Plant Biology	1,828	1,763	1,402	1,467	1,168	1,024	913	850	794	672
Research projects, etc.	88	70	80	123	138	76	118	190	107	115
General publications	137	63	80	67	76	91	66	62	78	59
Office of Administration	1,277	1,242	1,197	1,099	1,073	941	791	710	602	577
Professional fees, insurance, taxes	271	208	327	311	264	231	199	175	216	226
Retiree and special benefits	211	202	203	156	190	192	139	143	145	117
Investment services	690	389	411	395	385	342	278	308	265	238
Total expenses	16,070	16,002	14,425	13,599	13,588	10,816	9,589	9,012	8,481	8,576
Excess (deficiency) of revenues over expenses before capital changes	$ 8	$ 555	$ 294	$ 101	$ 413	$ 269	$ (334)	$(1,645)	$(1,838)	$(2,486)
Net realized and unrealized gain (loss) on investments	$45,731	$26,142	$(11,546)	$39,410	$(6,707)	$ 6,711	$ 7,430	$ 3,024	$(3,980)	$ (858)
Gifts—endowment and special funds	226	1,114	809	1,097	1,028	364	157	998	637	241
Market value of investments	202,982	153,210	130,805	137,859	95,759	101,464	94,359	86,425	84,136	89,287

Contributions, Gifts, and Grants for the Year Ended June 30, 1986

Joseph F. Albright
Joan M. Anderson
American Cancer Society
BARD (U. S.–Israel Agriculture Foundation)
Liselotte Beach
Giuseppe Bertani
Montgomery S. and Joanne Bradley
The Bristol-Myers Fund, Inc.
Donald D. Brown
Donald M. Burt
California Institute of Technology
Carnegie Corporation of New York
James F. Case
Ernst W. Caspari
Celanese Corporation
Britton Chance
People's Republic of China
The Jane Coffin Childs Memorial Foundation
John R. Coleman
Columbia University
Commonwealth Fund
Hayden G. Coon
Jean Cockrell Cowie
Sandy and George Dalsheimer
H. Clark Dalton
Robert L. DeHaan
Louis E. DeLanney
John Diebold
E. I. du Pont de Nemours
James and Alma Ebert
W. Gary Ernst
Exxon Education Foundation
Dorothy Ruth Fischer
George W. Fisher
Michael Fleischer
Scott Forbush Estate
Sibyl & William T. Golden Foundation
Crawford and Margaretta Greenewalt
William C. Greenough
Leo J. Haber
William G. Hagar, III
Richard Hallberg
Pembroke J. Hart
Caryl P. and Edna Haskins
Robert J. Hay
Ulrich Heber
Richard E. Heckert
Mary G. Hedger
H. Lawrence Helfer
Edward P. Henderson
Mark D. Henderson
Alfred D. Hershey
William R. Hewlett
William M. Hiesey
Alexander Hollaender
Satoshi Hoshina
Robert F. Howard
International Business Machines Corp.
F. Earl Ingerson
The J. I. Foundation, Inc.
George F. Jewett, Jr. 1965 Trust
The Johns Hopkins University
Paul A. Johnson
W. M. Keck Foundation
Elizabeth Ramsey, M.D., and Hans A. Klagsbrunn
Ursula and Irwin Konigsberg
David C. Koo
Robert W. Krauss
Faith W. and Arthur La Velle
Archibald H. Lawrence
Harold H. Lee
Ta-Yan Leong
Edna G. Lichtenstein
Melvyn Lieberman
Life Sciences Research Foundation
Eckhard Loos
Leukemia Society of America
John D. & Catherine T. MacArthur Foundation
John D. and Caroline Macomber
Sheila McCormick
Chester B. Martin, Jr.
The Andrew W. Mellon Foundation
Günter H. Moh
Ambrose Monell Foundation
Monsanto Company
Muscular Dystrophy Association
National Aeronautics and Space Administration
National Geographic Society
National Science Foundation
Office of Naval Research
Malcolm A. Nobs
Yasumi Ohshima
Tokindo Okada
Eijiro Ozawa
Richard S. Perkins
Pfizer Inc.
Pioneer Hi-Bred International, Inc.
Alexander Pogo
Public Health Service
P. R. Ranganayaki
Peter H. and Tamra E. Raven
Minocher Reporter
Curt P. Richter
Carl R. Robbins
Glenn C. Rosenquist

(continued)

Contributions, Gifts, and Grants for the Year Ended June 30, 1986 (continued)

Dorothea Rudnick
Damon Runyon–Walter Winchell Cancer Fund
Paul A. and Margaret H. Scherer
Maarten Schmidt
Robert C. Seamans, Jr.
Arindam Sen
Shell Companies Foundation, Inc.
Edwin M. Shook
Alfred P. Sloan Foundation
A. Ledyard Smith
Harold Speert
Ikuo Takeuchi
The Teagle Foundation, Inc.
George R. Tilton
Charles H. Townes
United Agriseeds
U. S. Agency for International Development
U. S. Department of Agriculture
U. S. Department of the Interior
University of California
University of Delaware
Albrecht Unsöld
William B. Upholt
Ken-ichi Wakamatsu
Sidney J. Weinberg, Jr. Foundation
James A. Weinman
Weizmann Institute
Wenner-Gren Foundation
Helen Hay Whitney Foundation
Frederick T. Wolf
Violet K. Young

1801 K Street, N.W.
Washington, DC 20006

Telephone 202 296 0800

Price Waterhouse

August 29, 1986

To the Auditing Committee of the
Carnegie Institution of Washington

In our opinion, the accompanying statements of assets, liabilities, and fund balances and the related statements of income, expenses, and changes in fund balances present fairly the financial position of the Carnegie Institution of Washington at June 30, 1986 and 1985, and the results of its operations and the changes in its fund balances for the years then ended, in conformity with generally accepted accounting principles applied on a consistent basis after restatement for the change, with which we concur, in the method of accounting for investments as described in Note 2 to the financial statements. Our examinations of these statements were made in accordance with generally accepted auditing standards and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

Our examinations were made for the purpose of forming an opinion on the basic financial statements taken as a whole. The supporting schedules 1 through 5 are presented for purposes of additional analysis and are not a required part of the basic financial statements. Such information has been subjected to the auditing procedures applied in the examination of the basic financial statements and, in our opinion, is fairly stated in all material respects in relation to the basic financial statements taken as a whole.

Price Waterhouse

Statements of Assets, Liabilities, and Fund Balances
June 30, 1986 and 1985

	1986	1985†
Assets		
Cash and cash equivalents	$ 598,514	$ 3,975,889
Advances	26,821	76,668
Grants receivable	213,077	393,639
Accrued interest and dividends	1,374,254	971,643
Due from brokers	262,534	649,040
	2,475,200	6,066,879
Investments* (market)		
Fixed income—short term	8,572,000	2,764,000
Fixed income—bonds	34,211,528	27,968,788
Fixed income—mortgages	29,842,106	24,161,102
Corporate stocks	129,712,137	97,767,778
Other	644,540	548,559
	202,982,311	153,210,227
Plant		
Land	1,019,524	1,019,524
Buildings	4,449,805	4,369,812
Equipment	10,224,309	10,218,544
	15,693,638	15,607,880
Total assets	$221,151,149	$174,884,986
Liabilities and Fund Balances		
Liabilities		
Accounts payable and accrued expenses	1,177,247	1,204,541
Deferred grant income	2,653,320	2,411,213
Total liabilities	3,830,567	3,615,754
Fund balances	217,320,582	171,269,232
Contingencies (see Note 6)	...	...
Total liabilities and fund balances	$221,151,149	$174,884,986

* Approximate cost on June 30, 1986: $160,152,977; June 30, 1985: $135,676,368.
† Restated for comparative purposes (see Note 2).

The accompanying notes are an integral part of these statements.

STATEMENTS OF REVENUES, EXPENSES, AND CHANGES IN FUND BALANCES FOR THE YEARS ENDED JUNE 30, 1986 AND 1985

	Year Ended June 30	
	1986	1985*
Revenues		
Investment income	$ 10,165,667	$ 11,196,173
Grants		
Federal	3,748,432	4,156,462
Private	1,847,049	1,042,142
Other revenues	317,496	162,933
Total revenues	16,078,644	16,557,710
Expenses		
Personnel and related	9,180,632	9,296,744
Equipment	1,598,870	1,880,666
General	5,291,078	4,825,015
Total expenses	16,070,580	16,002,425
Excess of revenues over expenses before capital changes	8,064	555,285
Capital changes		
Realized net gain on investments	20,435,855	8,066,121
Unrealized gain on investments	25,295,476	18,076,135
Gifts—Endowment and Special Funds	226,197	1,113,859
Land, buildings, and equipment capitalized	85,758	316,793
Sale of property	...	426,013
Total capital changes	46,043,286	27,998,921
Excess of revenues and capital changes over expenses	46,051,350	28,554,206
Fund balances, beginning of year	171,269,232	142,715,026
Fund balances, end of year	$217,320,582	$171,269,232

* Restated for comparative purposes (see Note 2).

The accompanying notes are an integral part of these statements.

NOTES TO THE FINANCIAL STATEMENTS
JUNE 30, 1986

Note 1. Significant Accounting Policies

The financial statements of the Institution are prepared on the accrual basis of accounting.

The Institution capitalizes expenditures for land, buildings, telescopes and other significant equipment, and construction projects in progress. Expenditures for other equipment are charged to current operations as incurred, and the cost of such other equipment is not capitalized. The Institution follows the policy of not depreciating its buildings and telescopes.

Note 2. Change in Method of Accounting for Investments

To allow for a better measurement of the value of its invested assets, the Institution changed its accounting policy relating to the valuation of investments in 1986. In prior years, investments were carried at the lower of cost or market. Under the new policy, which was applied retroactively, investments are carried at market, and increases or decreases in market value are recognized in the period in which they occur. There was no effect on the June 30, 1984 fund balances as previously reported, because the cost was written down to market value on that date. However, this change did increase unrealized gains on investments by $17,533,859 in 1985, and increased the June 30, 1985 fund balances by $17,533,859. Concurrent with this change, the Institution changed its method of determining gains and losses on the disposition of investments from the first-in, first-out method to the average cost method. This change had no material impact on the amount reported as realized net gain on investments.

A detailed listing of all securities held by the Institution as of June 30, 1986 has been included as Schedule 5 of this report.

Note 3. Employee Benefit Plans

The Institution has a noncontributory, money-purchase retirement plan, in which all United States personnel are eligible to participate. Voluntary contributions may also be made by employees. Actuarially determined contributions are funded currently by the Institution, and there are no unfunded past service costs. The total contributions made by the Institution were $778,743 in 1986 and $833,113 in 1985. Benefits under the plan upon retirement depend upon the investment performance of the Institution's Retirement Trust. After one year's participation, an individual's benefits are fully vested.

The Institution provides health insurance for retired employees. Most of the Institution's United States employees may become eligible for those benefits at retirement. The cost of retiree health insurance benefits is recognized as an expense as costs are incurred. For 1986 and 1985 those costs were $197,222 and $198,942, respectively.

Note 4. Restricted Grants

Restricted Grants are funds received from foundations, individuals, and federal agencies in support of scientific research and educational programs. The Institution follows the policy of reporting revenues only to the extent that reimbursable expenditures are incurred. The Restricted Grants Statement (Schedule 3) shows all current grants.

Note 5. Income Taxes

The Institution is exempt from federal income tax under Section 501(c)(3) of the Internal Revenue Code. Accordingly, no provision for income taxes is reflected in the accompanying financial statements. The Institution is also an educational institution within the meaning of Section 170(b)(1)(A)(ii) of the Code. The Internal Revenue Service has classified the Institution as other than a private foundation, as defined in Section 509(a) of the Code.

Note 6. Contingencies

During the fiscal year ended June 30, 1986, a suit was filed against the Institution alleging improper disposal of controlled hazardous substances removed from the Institution's Department of Embryology. The plaintiff seeks to obtain $23,000,000 compensatory damages and $23,000,000 punitive damages from the Institution. The Institution is vigorously defending itself against the charges brought in the suit. In the opinion of the Institution's management, the ultimate resolution of this matter will have no material effect on the financial position of the Institution.

Schedule 1

Schedule of Expenses by Department for the Years Ended June 30, 1986 and 1985

	1986				1985
	Endowment and Special	Restricted Grants Federal	Restricted Grants Private	Total Expenses	Total Expenses
Educational and scientific research expenses					
Terrestrial Magnetism	$ 1,769,730	$ 673,445	$ 429,973	$ 2,873,148	$ 2,946,883
Mount Wilson and Las Campanas Observatories	2,478,243	509,810	367,098	3,355,151	3,742,452
Geophysical Laboratory	1,729,936	489,717	179,186	2,398,839	2,391,292
Embryology	738,479	1,776,396	426,352	2,941,227	2,984,252
Plant Biology	1,110,249	298,459	419,440	1,828,148	1,762,989
Research projects, etc.	62,339	605	25,000	87,944	69,585
Total	7,888,976	3,748,432	1,847,049	13,484,457	13,897,453
Administrative and general expenses					
Office of Administration	1,277,068	...	...	1,277,068	1,242,331
General publications	137,371	...	...	137,371	63,150
Professional fees, insurance, and taxes	270,556	...	...	270,556	208,262
Retiree and special employee benefits	211,123	...	...	211,123	202,132
Investment services	690,005	...	...	690,005	389,097
Total	2,586,123	...	...	2,586,123	2,104,972
Total expenses	$10,475,099	$3,748,432	$1,847,049	$16,070,580	$16,002,425

The accompanying notes are an integral part of these schedules.

Schedule 2

Changes in Fund Balances for the Year Ended June 30, 1986

	Balance* July 1, 1985	Investment, Grant, and Other Income	Endowment and Special Gifts	Net Capital Gains Realized	Net Capital Gains Unrealized	Expenses	Other	Balance June 30, 1986
Endowment Funds								
Andrew Carnegie	$108,922,605	$ . . .	$ . . .	$14,563,643	$18,063,013	$ . . .	$ . . .	$141,549,261
Sybil & William T. Golden	44,767	. . .	. . .	5,986	7,424	. . .	. . .	58,177
Anonymous gifts	2,966,713	. . .	. . .	396,668	491,980	. . .	. . .	3,855,361
Mellon Matching	1,762,400	. . .	51,544	250,894	307,399	. . .	. . .	2,372,237
Astronomy Matching	1,895,141	. . .	. . .	253,392	314,278	. . .	. . .	2,462,811
Unrestricted Capital Funds								
Carnegie Corporation	33,178,060	. . .	. . .	4,109,458	5,051,435	. . .	. . .	42,338,953
Carnegie Futures	474,746	. . .	138,000	63,476	78,729	. . .	. . .	754,951
Vannevar Bush	243,519	. . .	. . .	32,560	40,384	. . .	. . .	316,463
Working Capital Fund	540,210	10,106,745	. . .	. . .	. . .	10,292,315	. . .	354,640
Restricted Grants	. . .	5,595,481	. . .	. . .	. . .	5,595,481	. . .	. . .
Special Funds								
Astronomy	1,865,480	127,012	. . .	257,300	317,195	. . .	. . .	2,566,987
Ira S. and Mary Bowen	637,216	41,584	. . .	83,898	103,453	34,396	. . .	831,755
Bush Gift	113,943	7,440	. . .	14,901	18,799	10,000	. . .	145,083
Colburn	565,303	37,988	. . .	76,230	97,056	37,000	. . .	739,577
Scott E. Forbush	. . .	. . .	36,603	. . .	. . .	. . .	. . .	36,603
Hale Relief	24,684	1,681	. . .	3,405	4,197	. . .	. . .	33,967
Harkavy	24,517	1,610	. . .	3,213	4,005	2,000	. . .	31,345
Lundmark	94,589	6,236	. . .	12,633	15,573	3,000	. . .	126,031
Morganroth	68,533	4,530	. . .	9,177	11,313	2,000	. . .	91,553
Moseley Astronomy	218,509	14,809	. . .	30,000	36,984	1,000	. . .	299,302
Francis L. Moseley Gift	128,988	8,782	. . .	17,791	21,932	. . .	. . .	177,493
Roberts Memorial	86,514	5,892	50	11,937	14,714	. . .	. . .	119,107
Special Instrumentation	294,309	20,038	. . .	40,593	50,043	. . .	. . .	404,983
Special Opportunities	178,321	12,141	. . .	24,595	30,321	. . .	. . .	245,378
Wood	1,332,285	86,675	. . .	174,105	215,249	93,388	. . .	1,714,926
Plant Fund	15,607,880	. . .	. . .	. . .	. . .	. . .	85,758	15,693,638
Totals	$171,269,232	$16,078,644	$226,197	$20,435,855	$25,295,476	$16,070,580	$85,758	$217,320,582

* Restated for comparative purposes (see Note 2).

The accompanying notes are an integral part of these schedules.

Schedule 3

Restricted Grants
for the Year Ended June 30, 1986

	Balance July 1, 1985	New Grants	Expenses	Balance June 30, 1986
Federal Grants				
BARD (U.S.–Israel Agriculture Fund)	$ 7,111	$ ...	$ 6,982	$ 129
National Aeronautics and Space Administration	207,226	219,403	265,183	161,446
National Science Foundation	1,185,676	995,709	1,237,827	943,558
Office of Naval Research	47,695	...	47,695	...
Public Health Service	912,381	1,948,742	1,836,961	1,024,162
U.S. Agency for International Development	88,225	...	62,672	25,553
U.S. Department of Agriculture	20,351	182,000	80,635	121,716
U.S. Department of the Interior	31,740	199,455	203,395	27,800
Other	4,640	27,087	7,082	24,645
Total federal grants	2,505,045	3,572,396	3,748,432	2,329,009
Private Grants				
American Cancer Society	662,783	16,000	85,024	593,759
California Institute of Technology	13,424	35,000	22,987	25,437
University of California	...	32,278	32,278	...
Carnegie Corporation of New York	250,000	...	125,000	125,000
People's Republic of China	186,233	...	171,193	15,040
The Jane Coffin Childs Memorial Fund for Medical Research	28,847	39,000	36,014	31,833
Columbia University	...	10,000	10,000	...
The Commonwealth Fund	...	2,500	1,522	978
The Charles A. Dana Foundation, Inc.	...	5,000	5,000	...
University of Delaware	...	14,844	...	14,844
Exxon Education Foundation	...	100,000	...	100,000
William R. Hewlett Lead Trust	1,248,665	997,425	828,367	1,417,723
Pioneer Hi-Bred International	19,501	...	9,682	9,819
Johns Hopkins University	12,295	61,295	37,065	36,525
W. M. Keck Foundation	198,811	...	58,148	140,663
Klingenstein Fund	...	5,000	5,000	...
Leukemia Society of America	...	76,140	...	76,140
Life Sciences Research Foundation	...	89,867	8,534	81,333
John D. & Catherine T. MacArthur Foundation	...	15,000	15,000	...
The Andrew W. Mellon Foundation	694,289	250,000	167,978	776,311
Ambrose Monell Foundation	...	50,000	...	50,000
Monsanto Company	21,136	...	15,543	5,593
Muscular Dystrophy Association	8,500	(9,000)	(500)	...
National Geographic Society	7,755	...	7,755	...
Richard B. T. Roberts	1,306	...	...	1,306
Vera C. Rubin	3,347	...	...	3,347
Damon Runyon–Walter Winchell Cancer Fund	63,480	20,500	57,819	26,161
Shell Development Company	...	78,570	39,929	38,641
Alfred P. Sloan Foundation	20,457	...	7,767	12,690
The Teagle Foundation, Inc.	10,000	30,000	30,250	9,750
United Agriseeds	1,917	30,000	30,000	1,917
Weizmann Institute	...	21,411	17,754	3,657
Wenner–Gren Foundation	5,364	...	4,847	517
Helen Hay Whitney Foundation	37,393	...	17,093	20,300
Total private grants	3,495,503	1,970,830	1,847,049	3,619,284
Total restricted grants	6,000,548	$5,543,226	$5,595,481	5,948,293
Less cash not yet received from grants	3,589,335			3,294,973
Deferred income	$2,411,213			$2,653,320

The accompanying notes are an integral part of these schedules.

Schedule 4

Schedule of Expenses
for the Years Ended June 30, 1986 and 1985

	1986			1985
	Endowment and Special	Restricted Grants	Total Expenses	Total Expenses
Salaries, fringe benefits, and payroll taxes				
Salaries	$ 5,139,558	$1,301,663	$ 6,441,221	$ 6,498,846
Fringe benefits and payroll taxes	1,319,630	353,267	1,672,897	1,764,141
Total	6,459,188	1,654,930	8,114,118	8,262,987
Fellowship grants	546,212	483,604	1,029,816	989,052
Awards, grants, and honoraria	23,093	13,605	36,698	44,705
Equipment				
Educational and research	216,880	999,933	1,216,813	1,274,421
Administrative and operating	159,644	14,440	174,084	130,137
Library	122,215	...	122,215	109,712
Buildings (improvement)	2,826	77,167	79,993	359,671
Telescopes (improvement)	5,765	...	5,765	6,725
Total	507,330	1,091,540	1,598,870	1,880,666
General expenses				
Educational and research supplies	664,428	1,009,109	1,673,537	1,641,307
Building maintenance	830,679	29,512	860,191	878,859
Investment services	690,005	...	690,005	389,097
Administrative	685,448	38,852	724,300	658,521
Travel	309,736	219,136	528,872	494,485
Retiree and special employee benefits	211,123	...	211,123	202,132
General insurance	164,614	...	164,614	56,762
Publications	127,610	35,643	163,253	156,122
Professional and consulting fees	111,832	7,681	119,513	209,728
Commissary	35,293	...	35,293	49,954
Shop	34,136	...	34,136	37,086
Real estate and other taxes	65,409	...	65,409	29,751
Rent	5,832	15,000	20,832	21,211
Total	3,936,145	1,354,933	5,291,078	4,825,015
Indirect costs	(996,869)	996,869	...	...
Total expenses	$10,475,099	$5,595,481	$16,070,580	$16,002,425

The accompanying notes are an integral part of these schedules.

Schedule of Investments
June 30, 1986

Description	Par/Shares	Cost	Approximate Market
Fixed income—short term			
General Motors Acceptance Corp., Master Note	3,474,000	$ 3,474,000	$ 3,474,000
Merck & Co. Inc., Master Note	2,438,000	2,438,000	2,438,000
Mobil Oil P & E, Master Note	2,660,000	2,660,000	2,660,000
Total fixed income—short term		8,572,000	8,572,000
Fixed income—bonds			
Chrysler Corp. Bonds, 13%, 1997	875,000	996,346	1,063,125
Chrysler Financial Corp., Note, 12.75%, 1994	450,000	502,034	565,875
DMK Bundes Republic, 7.25%, 1995	600,000	304,180	295,361
DMK Bundes Republic, 7.625%, 1995	400,000	204,162	200,773
DMK Bundes Republic, 7.5%, 1995	550,000	277,997	275,124
Equitable Life Leasing Corp., Note, 11.85%, 1988	13,609	13,850	13,609
Ford Motor Credit Co., Med Term Note, 8.125%, 1991	1,800,000	1,800,000	1,806,750
Household Finance Corp., Sr. Note 12.25%, 2004	200,000	273,738	261,000
International Bank Reconstruction & Development, 10%, 2001	340,000	371,850	372,725
Occidental Petroleum Corp., Note, 9.64%, 1992	1,200,000	1,213,000	1,134,000
Phillips Petroleum Co., SR Notes, 8.625%, 1995	450,000	446,085	380,250
Student Loan Marketing Assn., 13.5%, 1991	1,065,000	746,148	726,026
Sweden Kingdom Bonds, 10.25%, 2015	350,000	402,000	402,500
British Columbia Hydro & Power, Canadian Bonds, 15%, 2011	350,000	506,296	502,250
Government of Canada, Ser H48, Canadian Bonds, 11.75%, 1995	1,500,000	1,135,925	1,231,239
Government of Canada, Ser J95, Canadian Bonds, 11.75%, 1992	360,000	283,411	291,275
Government of Canada, Ser H67, Canadian Bonds, 10.75%, 1995	240,000	188,510	189,421
United States Treasury Notes, 13.75%, 1992	835,000	1,014,686	1,072,975
United States Treasury Note, 13.875%, 1989	4,000,000	4,687,500	4,688,800
United States Treasury Note, 11.375%, 1988	5,000,000	5,421,875	5,412,000
United States Treasury Note, 11.75%, 2001	2,505,000	3,272,156	3,328,519
United States Treasury Note, 10.75%, 2003	1,400,000	1,839,187	1,758,750
United States Treasury Bond, 10.50%, 1987	5,000,000	5,185,156	5,162,000
United States Treasury Bond, 10.75%, 2003	1,235,000	1,558,755	1,551,469
United States Treasury Bond, 11.625%, 2002	400,000	507,750	532,000
United States Treasury Bond, 11.875%, 2003	730,000	1,043,444	993,712
Total fixed income—bonds		34,196,041	34,211,528

The accompanying notes are an integral part of these schedules.

(continued)

Schedule 5
2 of 5

Schedule of Investments, June 30, 1986 (continued)

Description	Par/Shares	Cost	Approximate Market
Fixed income—mortgages			
FHLMC, Group #140152, 7.5%, 2009	915,514	$ 830,543	$ 830,829
FHLMC, Group #140639, 7.5%, 2007	1,358,193	1,256,328	1,235,955
FHLMC, Group #160027, 8.25%, 2007	2,517,331	2,438,664	2,363,144
FHLMC, Group #181062, 6%, 2008	2,433,079	1,350,354	2,128,945
FHLMC, Group #183340, 8.75%, 2008	922,242	872,671	877,282
FHLMC, Group #183370, 7.75%, 2007	1,537,130	1,416,835	1,425,689
FHLMC, Group #185180, 8.75%, 2008	2,694,942	2,147,532	2,580,407
FHLMC, Group #270349, 8%, 2008	1,723,503	1,640,560	1,609,321
FHLMC, Group #272191, 8%, 2009	889,450	858,975	833,116
FNMA, Pool #280, 8.5%, 2012	3,586,238	2,402,779	3,411,409
FNMA, Pool #1149, 8%, 2009	3,923,359	2,942,519	3,668,341
FNMA, Pool #19639, 8%, 2006	549,492	515,149	515,149
FNMA, Pool #19692, 7%, 2006	2,035,385	1,774,601	1,829,302
FNMA, Pool #20346, 8.25%, 2007	420,839	362,944	396,641
Dedham Institution for Savings, 8.198%, 2003	2,877,714	2,427,612	2,658,289
Home Savings American, VA/FHA, 9.907%, 2003	1,056,225	875,346	1,044,342
Security Savings, Scottsdale, 7.812%, 1999	2,656,420	2,146,573	2,433,945
Total fixed income—mortgages		26,259,985	29,842,106
Corporate stocks—common			
AMR Corp.	5,950	256,569	327,994
Abbott Laboratories	27,600	862,652	1,483,500
Advanced Micro Devices, Inc.	17,425	503,308	348,500
Aetna Life & Casualty Co.	5,525	239,712	334,953
H. F. Ahmanson & Co.	72,000	1,492,534	1,989,000
Alcan Aluminium Ltd.	3,400	103,057	103,700
Alexander & Alexander Services	12,500	462,421	492,188
Alexander & Baldwin, Inc.	5,737	157,248	215,156
Allied-Signal, Inc.	3,400	161,432	152,575
Aluminum Co. of America	29,410	910,885	1,121,256
Amax, Inc.	11,900	190,391	157,675
American General Corp.	10,500	430,697	442,313
American Home Products Corp.	8,825	552,174	794,250
American Information Technologies	18,680	1,290,913	2,552,155
American President Co.	20,400	376,383	489,600
Archer-Daniels-Midland Co.	11,602	157,866	211,746
Arvin	18,133	269,263	605,189
Associated Dry Goods Corp.	8,000	312,165	524,000
Atlantic Richfield Co.	850	54,468	44,200
Avon Products, Inc.	10,795	223,395	385,921
Baltimore Gas & Electric Co.	5,100	125,944	165,113
Bank of Boston Corp.	29,000	887,948	1,174,500
Barnett Banks of Florida, Inc.	8,500	239,773	486,625
Bausch & Lomb, Inc.	24,225	663,894	944,775
Bayer Industries, Inc.	595	79,858	78,094
Becton Dickinson & Co.	14,100	425,862	777,263
Bell Atlantic Corp.	27,610	931,000	1,918,895
Black & Decker Corp. (The)	11,050	203,912	226,525
Boeing Co.	51,408	2,054,808	3,238,704
Boise Cascade Corp.	8,075	358,093	468,350
CPC International Inc.	2,550	125,154	186,150
Calmat	15,300	380,972	535,500
Caterpillar Tractor Co.	18,785	691,016	934,554
Champion International Corp.	17,000	390,621	418,625

The accompanying notes are an integral part of these schedules. *(continued)*

Schedule 5
3 of 5

Schedule of Investments, June 30, 1986 (continued)

Description	Par/Shares	Cost	Approximate Market
Corporate stocks—common (continued)			
Chevron Corp.	2,635	$ 101,466	$ 101,118
Chrysler Corp.	11,700	314,755	446,063
Chubb Corp. (The)	10,900	595,254	752,100
Cigna Corp.	3,910	235,900	247,796
Citicorp	7,000	433,412	418,250
Coca-Cola Co.	36,300	864,356	1,520,063
Commonwealth Edison Co.	3,485	100,045	111,956
Computer Sciences Corp.	8,500	202,385	334,688
Computervision Corp.	2,210	22,614	30,664
Control Data Corp.	2,805	50,609	63,113
Cross Co. (A.T.)	4,165	129,213	178,574
Cypress Minerals Corp.	8,500	188,918	192,313
Dana Corp.	10,500	231,803	345,188
Data General Corp.	3,400	129,897	117,725
Deere & Co.	6,205	172,691	176,843
Delta Air Lines, Inc.	9,350	386,954	388,025
Digital Equipment Corp.	30,550	1,630,116	2,619,663
Dominion Resources, Inc.	1,700	57,494	71,400
Dow Chemical Co.	21,335	678,696	1,224,096
Dresser Industries, Inc.	8,670	174,497	161,479
Duke Power Co.	5,100	154,632	230,137
E. I. du Pont de Nemours	3,570	197,397	297,203
Eastman Kodak Co.	7,649	337,202	448,423
Economics Laboratory, Inc.	3,315	95,207	193,513
Emerson Electric Co.	11,660	871,764	1,014,420
FPL Group Inc.	1,700	48,464	53,975
Farmers Group Inc.	75,800	2,276,847	3,183,600
Federal Express Corp.	24,650	978,117	1,411,213
First Interstate Bancorp.	7,000	389,200	437,500
First of America Bank Corp.	9,000	386,250	470,250
First Union Corp.	22,000	258,500	629,750
Ford Motor Corp.	8,287	226,819	456,848
General Electric Co.	25,210	1,632,015	2,042,010
General Motors Corp.	8,075	547,697	626,822
General Motors Class H	446	16,683	18,565
General Public Utilities Corp.	46,751	602,981	981,771
General Re Corp.	14,450	740,934	903,125
Gillette Co.	18,400	583,813	903,900
Golden West Financial Corp.	12,000	452,940	508,500
Goodyear Tire & Rubber Co.	4,250	124,759	140,250
Great American First Savings Bank, San Diego	20,550	374,181	477,788
Great Western Financial Corp.	30,500	1,309,278	1,456,375
Henley Group Inc.	850	17,850	16,363
Hewlett-Packard Co.	18,950	664,560	776,950
Home Federal Savings & Loan Assn. of San Diego	10,500	398,491	393,750
Honeywell Inc.	1,275	77,006	96,581
ITT Corp.	10,000	459,728	543,750
Intel Corp.	8,500	230,031	195,500
International Business Machines Corp.	40,140	4,901,740	5,880,510
International Paper Co.	680	37,218	42,755
Jaguar PLC Sponsored ADR	23,000	156,170	196,926
Johnson & Johnson	59,350	2,777,497	4,310,294
K-Mart Corp.	4,080	139,847	232,050
Kroger Co. (The)	6,120	272,400	366,435
LSI Logic Corp.	4,462	62,900	44,067
Lilly & Company (Eli)	27,625	1,098,906	2,234,172

The accompanying notes are an integral part of these schedules. *(continued)*

SCHEDULE 5
4 OF 5

SCHEDULE OF INVESTMENTS, JUNE 30, 1986 (continued)

Description	Par/Shares	Cost	Approximate Market
Corporate stocks—common (continued)			
Long Island Lighting Co.	3,400	$ 31,652	$ 42,500
Lucky Stores Inc.	14,195	282,670	422,301
MCA Inc.	10,200	351,140	520,200
Mack Trucks Inc.	11,220	127,065	136,043
Marsh & McLennan Companies, Inc.	6,000	251,920	354,000
Maryland National Bank	15,400	230,037	754,600
McDonald's Corp.	15,225	677,055	1,113,328
Mead Corporation (The)	20,825	827,665	1,067,281
Medtronic, Inc.	13,600	781,151	1,037,000
Melville Corp.	14,000	881,084	994,000
Merck & Co., Inc.	14,000	785,570	1,463,000
Milipore Corp.	248	5,006	8,494
Minnesota Mining & Mfg. Co.	19,850	1,728,179	2,257,937
Mobile Corp.	8,585	261,868	271,501
Monsanto Co.	6,800	436,722	507,450
Moore Financial Group, Inc.	20,500	552,375	563,750
Philip Morris Inc.	26,610	712,491	1,985,771
Motorola, Inc.	17,850	565,705	711,769
NCNB Corp.	8,500	202,923	459,000
NWA, Inc.	20,400	788,972	1,020,000
National Australia Bank, Ltd.	178,000	520,640	667,500
Nike, Inc.	12,240	136,892	238,680
Northeast Utilities	8,670	142,364	187,489
Norwest Corp.	10,000	257,794	376,250
Nynex Corp.	27,600	853,435	1,863,000
Pacific Telesis Group	3,740	148,432	209,907
Penney Co., Inc. (J.C.)	3,230	150,825	275,358
Pepsico, Inc.	27,600	559,434	931,500
Pfizer Inc.	13,800	670,717	986,700
Salomon Inc.	15,900	601,326	773,137
Polaroid Corp.	26,350	796,764	1,923,550
Procter & Gamble Co.	4,845	252,885	388,206
Public Service Enterprise Group	6,290	163,540	235,089
Raytheon Co.	6,375	286,493	405,609
R. J. R. Nabisco	23,994	864,385	1,271,682
Rohm & Haas Co.	22,100	438,176	734,825
Royal Dutch Petroleum Co.	3,570	212,457	287,385
Safeway Stores, Inc.	4,675	138,824	251,281
San Diego Gas & Electric Co.	5,185	179,245	187,308
Schering-Plough Corp.	13,609	729,190	1,148,259
Schlumberger Ltd.	3,060	120,732	105,187
Shawmut Corp.	9,700	263,517	491,062
Skyline Corp.	8,500	114,468	132,812
SmithKline Beckman Corp.	15,950	1,121,845	1,598,987
Sony Corp.	11,050	179,684	222,381
Southern California Edison Co.	5,100	132,319	160,012
Southeast Banking Corp.	26,900	539,158	1,190,325
Southland Corp.	5,015	244,063	274,571
Southwestern Bell Corp.	2,295	146,113	251,302
Square D Co.	3,400	124,430	145,350
Tandem Computers Inc.	31,450	590,018	974,950
Tektronix, Inc.	16,150	938,788	966,981
Temple Inland, Inc.	17,850	635,367	910,350
Tenneco Inc.	6,460	251,041	256,785
Texas Instruments Inc.	1,360	149,928	162,350

The accompanying notes are an integral part of these schedules. *(continued)*

Schedule 5
5 of 5

Schedule of Investments, June 30, 1985 (continued)

Description	Par/Shares	Cost	Approximate Market
Corporate stocks—common (continued)			
Texas Utilities Co.	4,845	$ 135,216	$ 148,378
The Times Mirror Co.	1,700	95,032	118,575
The Timken Co.	9,691	461,863	471,225
Travelers Corp.	8,500	425,368	425,000
UAL Inc.	18,700	782,609	1,026,162
Upjohn Corp.	23,375	1,045,827	2,211,859
USF&G Corp.	4,590	152,168	183,026
US Life Corp.	4,335	179,498	209,164
US West	29,560	877,377	1,629,495
United States Steel Corp.	17,300	455,917	356,812
United States Tobacco Co.	9,500	396,340	404,937
United Technologies Corp.	24,945	974,782	1,234,777
Warner-Lambert Co.	19,000	831,612	1,175,625
Washington Gas Light Co.	5,100	97,792	148,537
Westpac Banking Corp.	178,000	505,920	578,500
Westinghouse Electric Corp.	11,500	266,076	616,687
Whirlpool Corp.	3,500	258,923	272,562
Xerox Corp.	22,995	1,308,088	1,290,594
Subtotal corporate stocks—common		80,554,434	115,424,662
Corporate stocks—preferred			
United Technologies Corp.	5,600	196,630	217,700
Subtotal corporate stocks—preferred		196,630	217,700
Corporate stocks—mutual fund			
Miller, Anderson & Sherrerd Value Fund	375,494	9,729,347	14,069,775
Subtotal corporate stocks—mutual fund		9,729,347	14,069,775
Total corporate stocks		90,480,411	129,712,137
Other			
Alan Dressler, Second trust, variable interest rate		58,423	58,423
James D. & Alma C. Ebert (noninterest-bearing loan to president secured by real estate)		200,000	200,000
Christopher Field, First trust, 8%, 2110		99,753	99,753
Arthur Grossman, First trust, 9.0%, 2114		92,406	92,406
Steven McKnight, First trust, 10.5%, 2114		98,329	98,329
François Schweizer, First trust, 10.5%, 2007		95,629	95,629
Total other		644,540	644,540
Total investments		$ 160,152,977	$ 202,982,311

The accompanying notes are an integral part of these schedules.

Articles of Incorporation

Fifty-eighth Congress of the United States of America;

At the Second Session,

Begun and held at the City of Washington on Monday, the seventh day of December, one thousand nine hundred and three.

AN ACT

To incorporate the Carnegie Institution of Washington.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the persons following, being persons who are now trustees of the Carnegie Institution, namely, Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, Samuel P. Langley, William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, Ethan A. Hitchcock, Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, their associates and successors, duly chosen, are hereby incorporated and declared to be a body corporate by the name of the Carnegie Institution of Washington and by that name shall be known and have perpetual succession, with the powers, limitations, and restrictions herein contained.

SEC. 2. That the objects of the corporation shall be to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind; and in particular—

(a) To conduct, endow, and assist investigation in any department of science, literature, or art, and to this end to cooperate with governments, universities, colleges, technical schools, learned societies, and individuals.

(b) To appoint committees of experts to direct special lines of research.

(c) To publish and distribute documents.

(d) To conduct lectures, hold meetings, and acquire and maintain a library.

(e) To purchase such property, real or personal, and construct such building or buildings as may be necessary to carry on the work of the corporation.

(f) In general, to do and perform all things necessary to promote the objects of the institution, with full power, however, to the trustees hereinafter appointed and their successors from time to time to modify the conditions and regulations under which the work shall be carried on, so as to secure the application of the funds in the manner best adapted to the conditions of the time, provided that the objects of the corporation shall at all times be among the foregoing or kindred thereto.

Sec. 3. That the direction and management of the affairs of the corporation and the control and disposal of its property and funds shall be vested in a board of trustees, twenty-two in number, to be composed of the following individuals: Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, Samuel P. Langley, William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, Ethan A. Hitchcock, Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, who shall constitute the first board of trustees. The board of trustees shall have power from time to time to increase its membership to not more than twenty-seven members. Vacancies occasioned by death, resignation, or otherwise shall be filled by the remaining trustees in such manner as the by-laws shall prescribe; and the persons so elected shall thereupon become trustees and also members of the said corporation. The principal place of business of the said corporation shall be the city of Washington, in the District of Columbia.

Sec. 4. That such board of trustees shall be entitled to take, hold and administer the securities, funds, and property so transferred by said Andrew Carnegie to the trustees of the Carnegie Institution and such other funds or property as may at any time be given, devised, or bequeathed to them, or to such corporation, for the purposes of the trust; and with full power from time to time to adopt a common seal, to appoint such officers, members of the board of trustees or otherwise, and such employees as may be deemed necessary in carrying on the business of the corporation, at such salaries or with such remuneration as they may deem proper; and with full power to adopt by-laws from time to time and such rules or regulations as may be necessary to secure the safe and convenient transaction of the business of the corporation; and with full power and discretion to deal with and expend the income of the corporation in such manner as in their judgment will best promote the objects herein set forth and in general to have and use all powers and authority necessary to promote such objects and carry out the purposes of the donor. The said trustees shall have further power from time

to time to hold as investments the securities hereinabove referred to so transferred by Andrew Carnegie, and any property which has been or may be transferred to them or such corporation by Andrew Carnegie or by any other person, persons, or corporation, and to invest any sums or amounts from time to time in such securities and in such form and manner as are permitted to trustees or to charitable or literary corporations for investment, according to the laws of the States of New York, Pennsylvania, or Massachusetts, or in such securities as are authorized for investment by the said deed of trust so executed by Andrew Carnegie, or by any deed of gift or last will and testament to be hereafter made or executed.

SEC. 5. That the said corporation may take and hold any additional donations, grants, devises, or bequests which may be made in further support of the purposes of the said corporation, and may include in the expenses thereof the personal expenses which the trustees may incur in attending meetings or otherwise in carrying out the business of the trust, but the services of the trustees as such shall be gratuitous.

SEC. 6. That as soon as may be possible after the passage of this Act a meeting of the trustees hereinbefore named shall be called by Daniel C. Gilman, John S. Billings, Charles D. Walcott, S. Weir Mitchell, John Hay, Elihu Root, and Carroll D. Wright, or any four of them, at the city of Washington, in the District of Columbia, by notice served in person or by mail addressed to each trustee at his place of residence; and the said trustees, or a majority thereof, being assembled, shall organize and proceed to adopt by-laws, to elect officers and appoint committees, and generally to organize the said corporation; and said trustees herein named, on behalf of the corporation hereby incorporated, shall thereupon receive, take over, and enter into possession, custody, and management of all property, real or personal, of the corporation heretofore known as the Carnegie Institution, incorporated, as hereinbefore set forth under "An Act to establish a Code of Law for the District of Columbia, January fourth, nineteen hundred and two," and to all its rights, contracts, claims, and property of any kind or nature; and the several officers of such corporation, or any other person having charge of any of the securities, funds, real or personal, books or property thereof, shall, on demand, deliver the same to the said trustees appointed by this Act or to the persons appointed by them to receive the same; and the trustees of the existing corporation and the trustees herein named shall and may take such other steps as shall be necessary to carry out the purposes of this Act.

SEC. 7. That the rights of the creditors of the said existing corporation known as the Carnegie Institution shall not in any manner be impaired by the

passage of this Act, or the transfer of the property hereinbefore mentioned, nor shall any liability or obligation for the payment of any sums due or to become due, or any claim or demand, in any manner or for any cause existing against the said existing corporation, be released or impaired; but such corporation hereby incorporated is declared to succeed to the obligations and liabilities and to be held liable to pay and discharge all of the debts, liabilities, and contracts of the said corporation so existing to the same effect as if such new corporation had itself incurred the obligation or liability to pay such debt or damages, and no such action or proceeding before any court or tribunal shall be deemed to have abated or been discontinued by reason of the passage of this Act.

Sec. 8. That Congress may from time to time alter, repeal, or modify this Act of incorporation, but no contract or individual right made or acquired shall thereby be divested or impaired.

Sec. 9. That this Act shall take effect immediately.

J G Cannon

Speaker of the House of Representatives.

Wm P Frye

President of the Senate pro tempore.

Approved.
April 28. 1904.
Theodore Roosevelt

By-Laws of the Institution

Adopted December 13, 1904. Amended December 13, 1910, December 13, 1912, December 10, 1937, December 15, 1939, December 13, 1940, December 18, 1942, December 12, 1947, December 10, 1954, October 24, 1957, May 8, 1959, May 13, 1960, May 10, 1963, May 15, 1964, March 6, 1967, May 3, 1968, May 14, 1971, August 31, 1972, May 9, 1974, April 30, 1976, May 1, 1981, May 7, 1982, May 3, 1985, and May 9, 1986.

ARTICLE I

The Trustees

1.1. The Board of Trustees shall consist of twenty-four members with power to increase its membership to not more than twenty-seven members.

1.2. The Board of Trustees shall be divided into three classes each having eight or nine members. The terms of the Trustees shall be such that those of the members of one class expire at the conclusion of each annual meeting of the Board. At each annual meeting of the Board vacancies resulting from the expiration of Trustees' terms shall be filled by their re-election or election of their successors. Trustees so re-elected or elected shall serve for terms of three years expiring at the conclusion of the annual meeting of the Board in the third year after their election. A vacancy resulting from the resignation, death, or incapacity of a Trustee before the expiration of his* term may be filled by election of a successor at or between annual meetings. A person elected to succeed a Trustee before the expiration of his term shall serve for the remainder of that term. There shall be no limit on the number of terms for which a Trustee may serve, and a Trustee shall be eligible for immediate re-election upon expiration of his term.

1.3. No Trustee shall receive any compensation for his services as such.

1.4. Trustees shall be elected by vote of two-thirds of the Trustees present at a meeting of the Board of Trustees at which a quorum is present or without a meeting by written action of all of the Trustees pursuant to Section 4.6.

1.5. If, at any time during an emergency period, there be no surviving Trustee capable of acting, the President, the Director of each existing Department, or such of them as shall then be surviving and capable of acting, shall constitute a Board of Trustees *pro tem*, with full powers under the provisions of the Articles of Incorporation and these By-Laws. Should neither the President nor any such Director be capable of acting, the senior surviving Staff Member of each existing Department shall be a Trustee *pro tem* with full powers of a Trustee under the Articles of Incorporation and these By-Laws. It shall be incumbent on the Trustees *pro tem* to reconstitute the Board with permanent members within a reasonable time after the emergency has passed, at which time the Trustees *pro tem* shall cease to hold office. A list of Staff Member seniority, as designated annually by the President, shall be kept in the Institution's records.

1.6. A Trustee who resigns after having served at least six years and having reached age seventy shall be eligible for designation by the Board of Trustees as a Trustee Emeritus. A Trustee Emeritus shall be entitled to attend meetings of the Board but shall have no vote and shall not be counted for purposes of ascertaining the presence of a quorum. A Trustee Emeritus may be invited to serve in an advisory capacity on any committee of the Board except the Executive Committee.

---

*A masculine pronoun as used in these By-Laws shall be deemed to include the corresponding female pronoun.

ARTICLE II

Officers of the Board

2.1. The officers of the Board shall be a Chairman of the Board, a Vice-Chairman, and a Secretary, who shall be elected by the Trustees, from the members of the Board, by ballot to serve for a term of three years. All vacancies shall be filled by the Board for the unexpired term; provided, however, that the Executive Committee shall have power to fill a vacancy in the office of Secretary to serve until the next meeting of the Board of Trustees.

2.2. The Chairman shall preside at all meetings and shall have the usual powers of a presiding officer.

2.3. The Vice-Chairman, in the absence or disability of the Chairman, shall perform the duties of the Chairman.

2.4. The Secretary shall issue notices of meetings of the Board, record its transactions, and conduct that part of the correspondence relating to the Board and to his duties.

ARTICLE III

Executive Administration

3.1. There shall be a President who shall be elected by ballot by, and hold office during the pleasure of, the Board, who shall be the chief executive officer of the Institution. The President, subject to the control of the Board and the Executive Committee, shall have general charge of all matters of administration and supervision of all arrangements for research and other work undertaken by the Institution or with its funds. He shall prepare and submit to the Board of Trustees and to the Executive Committee plans and suggestions for the work of the Institution, shall conduct its general correspondence and the correspondence with applicants for grants and with the special advisors of the Committee, and shall present his recommendations in each case to the Executive Committee for decision. All proposals and requests for grants shall be referred to the President for consideration and report. He shall have power to remove, appoint, and, within the scope of funds made available by the Trustees, provide for compensation of subordinate employees and to fix the compensation of such employees within the limits of a maximum rate of compensation to be established from time to time by the Executive Committee. He shall be *ex officio* a member of the Executive Committee.

3.2. The President shall be the legal custodian of the seal and of all property of the Institution whose custody is not otherwise provided for. He shall sign and execute on behalf of the corporation all contracts and instruments necessary in authorized administrative and research matters and affix the corporate seal thereto when necessary, and may delegate the performance of such acts and other administrative duties in his absence to other officers. He may execute all other contracts, deeds, and instruments on behalf of the corporation and affix the seal thereto when expressly authorized by the Board of Trustees or Executive Committee. He may, within the limits of his own authorization, delegate to other officers authority to act as custodian of and affix the corporate seal. He shall be responsible for the expenditure and disbursement of all funds of the Institution in accordance with the directions of the Board and of the Executive Committee, and shall keep accurate accounts of all receipts and disbursements. He shall, with the assistance of the Directors of the Departments, prepare for presentation to the Trustees and for publication an annual report on the activities of the Institution.

3.3. The President shall attend all meetings of the Board of Trustees.

3.4. The corporation shall have such other officers as may be appointed by the Executive Committee, having such duties and powers as may be specified by the Executive Committee or by the President under authority from the Executive Committee.

3.5. The President shall retire from office at the end of the fiscal year in which he becomes sixty-five years of age.

ARTICLE IV

Meetings and Voting

4.1. The annual meeting of the Board of Trustees shall be held in the City of Washington, in the District of Columbia, in May of each year on a date fixed by the Executive Committee, or at such other time or such other place as may be designated by the Executive Committee, or if not so designated prior to May 1 of such year, by the Chairman of the Board of Trustees, or if he is absent or is unable or refuses to act, by any Trustee with the written consent of the majority of the Trustees then holding office.

4.2. Special meetings of the Board of Trustees may be called, and the time and place of meeting designated, by the Chairman, or by the Executive Committee, or by any Trustee with the written consent of the majority of the Trustees then holding office. Upon the written request of seven members of the Board, the Chairman shall call a special meeting.

4.3. Notices of meetings shall be given ten days prior to the date thereof. Notice may be given to any Trustee personally, or by mail or by telegram sent to the usual address of such Trustee. Notices of adjourned meetings need not be given except when the adjournment is for ten days or more.

4.4. The presence of a majority of the Trustees holding office shall constitute a quorum for the transaction of business at any meeting. An act of the majority of the Trustees present at a meeting at which a quorum is present shall be the act of the Board except as otherwise provided in these By-Laws. If, at a duly called meeting, less than a quorum is present, a majority of those present may adjourn the meeting from time to time until a quorum is present. Trustees present at a duly called or held meeting at which a quorum is present may continue to do business until adjournment notwithstanding the withdrawal of enough Trustees to leave less than a quorum.

4.5. The transactions of any meeting, however called and noticed, shall be as valid as though carried out at a meeting duly held after regular call and notice, if a quorum is present and if, either before or after the meeting, each of the Trustees not present in person signs a written waiver of notice, or consent to the holding of such meeting, or approval of the minutes thereof. All such waivers, consents, or approvals shall be filed with the corporate records or made a part of the minutes of the meeting.

4.6. Any action which, under law or these By-Laws, is authorized to be taken at a meeting of the Board of Trustees or any of the Standing Committees may be taken without a meeting if authorized in a document or documents in writing signed by all the Trustees, or all the members of the Committee, as the case may be, then holding office and filed with the Secretary.

4.7. During an emergency period the term "Trustees holding office" shall, for purposes of this Article, mean the surviving members of the Board who have not been rendered incapable of acting for any reason including difficulty of transportation to a place of meeting or of communication with other surviving members of the Board.

ARTICLE V

Committees

5.1. There shall be the following Standing Committees, *viz.* an Executive Committee, a Finance Committee, an Auditing Committee, a Nominating Committee, and an Employee Benefits Committee.

5.2. All vacancies in the Standing Committees shall be filled by the Board of Trustees at the next annual meeting of the Board and may be filled at a special meeting of the

Board. A vacancy in the Executive Committee and, upon request of the remaining members of any other Standing Committee, a vacancy in such other Committee may be filled by the Executive Committee by temporary appointment to serve until the next meeting of the Board.

5.3. The terms of all officers and of all members of Committees, as provided for herein, shall continue until their successors are elected or appointed. The term of any member of a Committee shall terminate upon termination of his service as a Trustee.

Executive Committee

5.4. The Executive Committee shall consist of the Chairman, Vice-Chairman, and Secretary of the Board of Trustees, the President of the Institution *ex officio*, and, in addition, not less than five or more than eight Trustees to be elected by the Board by ballot for a term of three years, who shall be eligible for re-election. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term. The presence of four members of the Committee shall constitute a quorum for the transaction of business at any meeting.

5.5. The Executive Committee shall, when the Board is not in session and has not given specific directions, have general control of the administration of the affairs of the corporation and general supervision of all arrangements for administration, research, and other matters undertaken or promoted by the Institution. It shall also submit to the Board of Trustees a printed or typewritten report of each of its meetings, and at the annual meeting shall submit to the Board a report for publication.

5.6. The Executive Committee shall have power to authorize the purchase, sale, exchange, or transfer of real estate.

Finance Committee

5.7. The Finance Committee shall consist of not less than five and not more than six members to be elected by the Board of Trustees by ballot for a term of three years, who shall be eligible for re-election. The presence of three members of the Committee shall constitute a quorum for the transaction of business at any meeting.

5.8. The Finance Committee shall have custody of the securities of the Institution and general charge of its investments and invested funds and shall care for and dispose of the same subject to the directions of the Board of Trustees. It shall have power to authorize the purchase, sale, exchange, or transfer of securities and to delegate this power. For any retirement or other benefit plan for the staff members and employees of the Institution, it shall be responsible for supervision of matters relating to investments, appointment or removal of any investment manager or advisor, reviewing the financial status and arrangements, and appointment or removal of any plan trustee or insurance carrier. It shall consider and recommend to the Board from time to time such measures as in its opinion will promote the financial interests of the Institution and improve the management of investments under any retirement or other benefit plan. The Committee shall make a report at the annual meeting of the Board.

Auditing Committee

5.9. The Auditing Committee shall consist of three members to be elected by the Board of Trustees by ballot for a term of three years.

5.10. Before each annual meeting of the Board of Trustees, the Auditing Committee shall cause the accounts of the Institution for the preceding fiscal year to be audited by public accountants. The accountants shall report to the Committee, and the Committee

shall present said report at the ensuing annual meeting of the Board with such recommendations as the Committee may deem appropriate.

Nominating Committee

5.11. The Nominating Committee shall consist of the Chairman of the Board of Trustees *ex officio* and, in addition, three Trustees to be elected by the Board by ballot for a term of three years, who shall not be eligible for re-election until after the lapse of one year. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term, provided that of the Nominating Committee first elected after adoption of this By-Law one member shall serve for one year, one member shall serve for two years, and one member shall serve for three years, the Committee to determine the respective terms by lot.

5.12. Sixty days prior to an annual meeting of the Board the Nominating Committee shall notify the Trustees by mail of the vacancies to be filled in membership of the Board. Each Trustee may submit nominations for such vacancies. Nominations so submitted shall be considered by the Nominating Committee, and ten days prior to the annual meeting the Nominating Committee shall submit to members of the Board by mail a list of the persons so nominated, with its recommendations for filling existing vacancies on the Board and its Standing Committees. No other nominations shall be received by the Board at the annual meeting except with the unanimous consent of the Trustees present.

Employee Benefits Committee

5.13. The Employee Benefits Committee shall consist of not less than three and not more than four members to be elected by the Board of Trustees by ballot for a term of three years, who shall be eligible for re-election, and the Chairman of the Finance Committee *ex officio*. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term.

5.14. The Employee Benefits Committee shall, subject to the directions of the Board of Trustees, be responsible for supervision of the activities of the administrator or administrators of any retirement or other benefit plan for staff members and employees of the Institution, except that any matter relating to investments or to the appointment or removal of any trustee or insurance carrier under any such plan shall be the responsibility of the Finance Committee. It shall receive reports from the administrator or administrators of the employee benefit plans with respect to administration, benefit structure, operation, and funding. It shall consider and recommend to the Board from time to time such measures as in its opinion will improve such plans and the administration thereof. The Committee shall submit a report to the Board at the annual meeting of the Board.

ARTICLE VI

Financial Administration

6.1. No expenditure shall be authorized or made except in pursuance of a previous appropriation by the Board of Trustees, or as provided in Section 5.8 of these By-Laws.

6.2. The fiscal year of the Institution shall commence on the first day of July in each year.

6.3. The Executive Committee shall submit to the annual meeting of the Board a full statement of the finances and work of the Institution for the preceding fiscal year and a detailed estimate of the expenditures of the succeeding fiscal year.

6.4. The Board of Trustees, at the annual meeting in each year, shall make general appropriations for the ensuing fiscal year; but nothing contained herein shall prevent the Board of Trustees from making special appropriations at any meeting.

6.5. The Executive Committee shall have general charge and control of all appropriations made by the Board. Following the annual meeting, the Executive Committee may allocate these appropriations for the succeeding fiscal year. The Committee shall have full authority to reallocate available funds, as needed, and to transfer balances.

6.6. The securities of the Institution and evidences of property, and funds invested and to be invested, shall be deposited in such safe depository or in the custody of such trust company and under such safeguards as the Finance Committee shall designate, subject to directions of the Board of Trustees. Income of the Institution available for expenditure shall be deposited in such banks or depositories as may from time to time be designated by the Executive Committee.

6.7. Any trust company entrusted with the custody of securities by the Finance Committee may, by resolution of the Board of Trustees, be made Fiscal Agent of the Institution, upon an agreed compensation, for the transaction of the business coming within the authority of the Finance Committee.

6.8. The property of the Institution is irrevocably dedicated to charitable purposes, and in the event of dissolution its property shall be used for and distributed to those charitable purposes as are specified by the Congress of the United States in the Articles of Incorporation, Public Law No. 260, approved April 28, 1904, as the same may be amended from time to time.

ARTICLE VII

Amendment of By-Laws

7.1. These By-Laws may be amended at any annual or special meeting of the Board of Trustees by a two-thirds vote of the members present, provided written notice of the proposed amendment shall have been served personally upon, or mailed to the usual address of, each member of the Board twenty days prior to the meeting.

Index